The Development of the Current State Buffer

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ABSTRACT

This thesis examines a component of Short Term Memory that is responsible for automatically tracking important stimuli in our immediate environment. The component has been termed the "Current State Buffer" (Abeles and Morton, submitted; Barreau, 1997; Barreau and Morton, submitted; Morton, 1997), and it is argued that current conceptions of the Working Memory model (e.g. Baddeley & Hitch, 1993) do not adequately specify its role as a separate functional element of Short Term Memory.

A Developmental perspective was adopted for investigating the Current State Buffer experimentally. The data was collected through the implementation of a novel task (the "Tidy Emu Paradigm"), which involved pre-school children watching an Emu glove puppet tidy away toys into receptacles. The paradigm employed dual-task methodology, consistent with many other studies of Working Memory.

The empirical work reported falls into three principal stages. The first demonstrates the Current State Buffer's existence as independent to Working Memory. The lack of interference between performance on a Current State Buffer task and a Visuospatial Sketchpad task was taken as evidence for this. Other explanations for the finding are considered, and further experiments replicate the basic finding.

The second stage analyses the architecture of a system that comprises a Current State Buffer and Working Memory. In brief, the data are best described by an architecture where information enters an Environmental Input Buffer, and depending on the nature of the stimulus, it passes either into the Current State Buffer, or into an Interpreter Buffer (Working Memory). At retrieval, the contents of these buffers can independently proceed to an Output Buffer.

The final stage explores the effects of increasing the load of the Current State Buffer task. This revealed age-related capacity limitations in Current State Buffer function, and that subjects used age-related strategies to deal with the increase in character load, involving interactions between the Current State Buffer and Working Memory.

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CHAPTER 1

"The Mirrors of the Present"

1.1 Introduction

> *"More time has been spent in the attics of memory than in the contemplation of the mirrors of the present"* (Richard Condon, A talent for loving, Book 2, Chapter 6).

The distinction between the "attics of memory" and the "mirrors of the present" is a compelling one. Regardless of whether people spend more time in one than the other, one feels that these are indeed two separate entities. Memory for things that are in the past are stored away high up in the attic. However, the "mirrors of the present" directly reflect the current reality, and are presumably in a well-lit place, available for "contemplation".[1] The contrast here is between Long Term Memory and Short Term Memory[2].

1.1.1 Thesis Outline

In this thesis I examine an aspect of Short Term Memory that is responsible for automatically encoding and tracking the important aspects of our immediate personal environment. This component has been termed the "Current State Buffer" (Morton, 1997). I argue that these representations are a part of Short Term Memory. No model of Short Term Memory to date has specified the nature of, or indeed the need for, what seems to be such a vital component of the Memory System. The empirical work establishes a new visuospatial task for pre-school children that is able to demonstrate the independence of the Current State Buffer from other known components of Short Term Memory. The characteristics of the Current State Buffer are then explored using this novel paradigm.

In this first chapter of the thesis, I will be exploring the concept of Short Term Memory as a separate entity, and consider some of the models that have been constructed to account for it. The basic Short Term Memory phenomena are discussed, and key problems with earlier models of Short Term Memory are highlighted. Baddeley and Hitch's (1974; 1993) Working Memory model is then presented, as it seems to rectify many of the inadequacies of former models. This particular model is then examined and

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[1] Perhaps this is the irony which is pointed out by Condon.

[2] I shall capitalise "Short Term Memory" and "Long Term Memory" when I refer to constructs that reflect different parts of the memory system. When not capitalised, the reference is to the paradigm of immediate testing versus delayed testing respectively (which have become associated with the constructs).

evaluated, and I shall claim that it can be used as a helpful heuristic in understanding Short Term Memory.

The second chapter investigates how the Working Memory model has been applied to cognitive development, focusing particularly on visuospatial tasks. The third chapter introduces the Current State Buffer formally, and discusses the one study that has employed this notion (Barreau and Morton, submitted). I then motivate how it may be possible to demonstrate the Current State Buffer's independence from Working Memory, and I justify my choice of subject population and task (the "Tidy Emu Paradigm"). In the fourth chapter I document how I used the "Tidy Emu Paradigm" to dissociate the Current State Buffer from Working Memory. This chapter ends with a discussion of some alternative explanations to the set of results obtained in the chapter.

Chapter 5 considers the alternative explanations to the basic finding of the previous chapter by documenting two further experiments that were carried out to counter these claims. Chapter 6 then considers the nature of the architecture of a system that includes a Current State Buffer, and the penultimate chapter investigates the capacity of the Current State Buffer and its interactions with Working Memory. The final chapter contains a summary of the thesis, and some concluding remarks relating to some of the issues generated by the work.

1.2 Short Term Memory

1.2.1 Short Term Memory as a Separate Entity

1.2.1.1 Early History and Early Models

John Locke (1690) was probably the first to distinguish between Long and Short Term Memory on introspective grounds, when he discriminated between a "storehouse of ideas" and the "idea in view". The concept of a distinct Short Term Memory emerged again a few centuries later in the writings of Galton (1883) where he referred to an "ante-chamber" of consciousness. William James (1905) contrasted what was remembered from current consciousness - "primary memory" and what involves knowledge that has been absent from consciousness - "secondary memory". Neither Locke, Galton nor James specified the nature of the these components of Memory, but it was clear to these authors that some memories are permanent records of the past, whereas others are a temporary representation of "the specious present" (James, 1905). Hebb (1949) developed the possibility that there might be two distinct neurophysiological structures in the brain that are separately responsible for the two types of memory. One involved temporary reverberating circuits, and the other formed what Hebb called "cell assemblies" of permanent links between cells.

Broadbent (1958) specified the first information processing model of Short Term Memory in his seminal book *Perception and Communication.* He explicitly assumed the need for two separate memory systems. A short-term system of a limited capacity held temporary memory traces which would spontaneously decay unless they were rehearsed. The long-term system was not limited in its capacity, and forgetting occurred when items interfered with one another at retrieval. Broadbent (1958) specified that there were two sub-components of the short-term system, the *S* and the *P Systems.* The S system was capable of receiving sensory input in parallel from various sources. The information could then be fed into the P system which had a limited capacity for storing and processing information. With time, the information would then decay unless it was rehearsed (Broadbent, 1963). The P system fed directly into Long Term Memory, which was not subject to decay, but to the interference of interpolated or similar items.

At this stage in summarising the history of Short Term Memory, it is worth mentioning that a controversy arose in the 1960's regarding the need to fractionate Long and Short Term Memory at all. This was largely based on the assertions of Melton (1963) who focused on the particular assumption of Broadbent's model that information in Short Term Memory would decay unless otherwise rehearsed. Melton claimed that traditional Short Term Memory tasks were governed instead by the tenets of interference theory. Since Long Term Memory phenomena were underpinned by interference theory, it seemed that there was no need for a theoretical distinction between Long and Short Term Memory. It is interesting to note that the basic thrust of the argument against a dichotomy, namely that Long Term Memory processes seem to underpin Short Term Memory, is still prevalent today, nearly forty years later (e.g. see Nairne, 1996). The validity of this argument is questioned a little later on, when I summarise the considerable evidence in favour of a dichotomy.

Melton's (1963) argument stimulated Waugh and Norman (1965) to make the important distinction between a hypothetical Short Term Memory store which they labelled *Primary Memory* (reviving William James' term), and the experimental short term memory paradigm that may sometimes underpin it. What is important here is that a short term memory task does not have to be a pure measure of Primary or Short Term Memory. Performance on short term memory tasks may reflect both "Primary Memory" and "Secondary Memory" systems, while delayed recall is likely to exclusively reflect "Secondary Memory". Primary Memory for Waugh and Norman was of fixed capacity, as in Broadbent's model, but it suffered from the displacement of older items by new material. In this model, the contents of Primary Memory are safeguarded if they are maintained by verbal rehearsal, which was also a mechanism through which information could be copied into Secondary Memory.

1. The Modal Model

Models of Short Term Memory then proliferated to such an extent that Baddeley (1986) conjectures that there were well over 25 models by the beginning of the 1970's. However, these models shared so many common features that they could be approximated to what was the most widely quoted model of the era, namely the model of Atkinson and Shiffrin (1968). This model was thus referred to by Murdock (1974) as the "Modal Model" as it contained the essence of all of these models. In effect, the Modal Model itself had many features in common with Broadbent's (1963) earlier model (Baddeley, 1990).

The Modal Model (Atkinson and Shiffrin, 1968) consisted of three separate stages of information flow. Input from the environment entered into a bank of modality-specific sensory buffer stores, (broadly corresponding to Broadbent's S system). All information then flowed through to the second stage, a limited capacity Short Term Store which could hold, manipulate and communicate information with the permanent Long Term Store. Transfer to the Long Term Store was a direct function of how long the information was kept in the Short Term Store. Control processes governed rehearsal of the contents of the Short Term Store, allowing information to stay there longer and increase the chances of transfer to the Long Term Store. Atkinson and Shiffrin's (1968) model dealt almost exclusively with the processing and storage of auditory-verbal-linguistic information. Although they did raise the possibility of a separate visual Short Term Store with rehearsal properties, it has become widely interpreted as a model comprising a single Short Term Store, because at the time, there was so little evidence to support this view (Logie, 1996). Note the crucial importance of the Short Term Store in the model, since without it information cannot get into or out of the Long Term Store.

2. Production-System Models

In their attempt to simulate human cognition using computer models, Newell and Simon (1972) developed an account of human problem solving. They postulated a Short Term Memory as a part of their "Production-System". Briefly, a Production-System is a collection of rules, an interpreter that decides when and how to apply the rules, and a Short Term Memory which holds data, goals, and intermediate results. Each rule consists of a set of conditions or premises, together with a set of actions or conclusions to be implemented or inferred if the relevant conditions hold.

Newell and Simon (1972) thus defined their component of Short Term Memory as the collection of information of which a subject is aware at any particular moment in time. Newell and Simon (1972) assumed that Short Term Memory contained a small number of symbolic expressions or "chunks", each of which could be a complex configuration of elements. Newell even entertained the notion that Short Term Memory was indefinitely large but unreliable, so that with longer sequences of items there would be an increasing probability that elements would be lost, which would lead to an effective limit on storage capacity as opposed to an absolute limit.

1.2.2 Evidence for Short Term Memory as a Separate Entity

1.2.2.1 Introduction

Thus far, I have supplied a brief history of Short Term Memory, and how the early models of Short Term Memory have described this construct. I have kept this discussion purely at a theoretical level, mentioning no evidence for the dichotomy, nor for the specific features of the models themselves. What immediately follows therefore, is a review of the evidence in favour of having a separate Short Term Memory system. Once this has been presented, the status of these early models can be evaluated through a consideration of these and other Short Term Memory phenomena.

1.2.2.2 Evidence for a Separation

1. Some Neuropsychology

The most powerful indication of a separation between Short and Long Term Memory comes from Milner's (1958) observations of patients with anterograde amnesia[3]. If one asks these patients to immediately recall lists of items in the order they were presented ("serial recall"), such that the number of items in the list is short enough to allow perfect recall on a very high percentage of trials, they perform as well as normal adults. With the proviso that one tests them immediately after the study phase, one can say that these patients perform normally on span tasks. Similarly, one can have a normal conversation with an amnesia sufferer without suspecting any mental abnormalities (until one leaves the room and returns to find they have forgotten who you are). Milner (1958) interpreted the syndrome as reflecting a fundamental inability to transfer information into a distinct Long Term Memory System. Because span tasks and ordinary conversation only require the ability to hold on to information for a short time, Milner asserted that these patients have intact Short Term Memory, although they were unable

[3] One of the most "famous" of these type of patients was HM, who became amnesic following bilateral hippocampal and temporal lobe excision that was carried out to relieve an intractable epilepsy (Milner, 1966).

to transfer information into Long Term Memory. Della Sala and Logie (1993) note that these are not isolated cases, and cite other patients with a similar pattern of selective impairment.

2. Coding

There are also apparent differences in the nature of the coding of items in Short and Long Term Memory. When Conrad (1964) asked his subjects to learn a string of letters in order, he found that memory performance was poorer when the letters sounded very similar to one another. Thus a sequence such as *D, C, B, T, P, V* was more difficult to retain than a sequence like *L, W, K, F, R, T*. Conrad discovered that this acoustic similarity effect disrupts the order of recall of the letters for Short Term serial recall, regardless of whether the items are read or heard by the subjects. Baddeley (1966) contrasted the recall of short sequences of acoustically similar words such as *'mad map man'* and acoustically dissimilar words such as *'bus clock spoon,'* with the recall of short sequences of semantically similar words such as *'hug big great'*. He found that with short term recall, the sets of acoustically similar words were less well recalled than were acoustically dissimilar words. However, the semantically similar words resulted in recall performance that was very little different from recall of semantically distinct words. In contrast, after a delay, the effect of acoustic similarity disappeared, but an effect of semantic similarity was still evident, with semantically similar words recalled less well than semantically different words. Since acoustic similarity appeared to affect short term storage and semantic similarity appeared to affect long term storage, it suggested that a short term storage system retains words in terms of their sounds (even with visually presented words) while the longer term system retains words in terms of their meaning.

On a more historical note, Morton (1964) had suggested at the time, that Conrad's results were in fact better termed "articulatory" errors rather than acoustic errors since the errors were phonological, rather than related to sound per se. Nevertheless, the effect is still widely termed an "acoustic" similarity effect.

3. Recency

The results of standard free-recall procedures can provide another important argument for the Short/Long Term Memory distinction. The free-recall task was first reported over a century ago by Nipher (1878). In it, subjects are presented with a long list of items and required to recall them in any order. The standard pattern of data is that subjects are more successful at recalling items that featured early on in the list, and late on in the list. The "recency effect" is the term used to describe the superior recall of the last few items relative to the middle items, and the "primacy effect" is the term used to refer to the superior recall of the first few items relative to the middle items. Relevant to the Short Term versus Long Term Memory distinction, is the finding that if recall is delayed by a distracting task, the recency effect is disrupted, whereas the primacy effect remains at the same level (Glanzer and Cunitz, 1966).

At its most simple understanding, the recency effect arises because the last few items are present in Short Term Memory at the time recall begins (Watkins, 1974), and decay or become displaced soon after. Similarly, the primacy effect is explained simply by positing that the earlier items in the list have been recalled from Long Term Memory. This notion is further supported by the fact that only the earlier items in the list are affected by variables that are known to influence Long Term Memory (e.g. rate of presentation, age of subject, word frequency and imageability (Glanzer, 1972)), whereas the recency effect is only sensitive to delay.

This explanation of the recency effect is not the only way one can explain these curves. It is true that recency effects are not just confined to the conventional free recall task[4] (Bjork and Whitten, 1974), and they also seem to occur in recall of events that occurred weeks or months earlier (Baddeley and Hitch, 1977). Recency may be attributable to the use of temporally based strategies for retrieving items from memory in general. Given that this is the case, some have claimed that it is not necessary to conceive of a dichotomy between Short and Long Term Memory (Crowder, 1993).[5]

4. More Neuropsychology

The argument against a separate Short Term Memory based on this alternative explanation to recency effects sounds reasonable, but it fails to take into account certain empirical facts which argue in favour of the Short/Long Term Memory distinction. Baddeley and Warrington (1970) documented that anterograde amnesics show an intact recency effect but typically recall little else from the remainder of the list. This is consistent with the hypothesis that amnesics have an intact Short Term Memory, but are unable to transfer items to Long Term Memory (see above). It is not clear how a retrieval strategy explanation would account for this. In addition, it is not clear how proponents of this position would explain the disruption to the recency effect when a distracting task precedes free recall (Glanzer and Cunitz, 1966).

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[4] The recency effects found in *conventional* free recall tasks however, are susceptible to delay: whereas the other effects are not susceptible to delay. One may argue therefore, that we are dealing with two separate phenomena.

[5] Note the logic of this argument. Because recency also exists in Long Term Memory, there is no need to invoke the concept of a separate Short Term Memory system. In obviating the need for two Memory Systems this logic is similar to Melton's (1963) reasoning against having two systems in saying that interference is in common with both Long and Short Term Memory.

The most compelling counter-argument to a "one system" view though, is the behaviour of patients who have suffered brain damage which leaves them with a digit span of only one or two items. According to a dual-memory theory, this reflects a defect in (verbal) Short Term Memory. Furthermore, these patients also have peculiarly shaped recency effects, decreased to little more than the last item of the list (Shallice and Warrington, 1979).

Finally, consider what happens when these patients are tested in the situations that produce the long-term recency effects described above. In these tasks, the patients' performance seems indistinguishable from normals (Vallar, Papagno and Baddeley, 1991). It is difficult to interpret these findings without somehow postulating a distinct Short Term Memory responsible for the conventional free recall recency effect. Thus the recency data seem to provide support for the traditional interpretation of recency in free recall, and taken together with the other evidence, it provides good evidence for the Short/Long Term Memory distinction. Long-term recency effects may turn out to have a different source than the conventional recency effect[6].

5. Capacity and Speed of Processing

Further evidence for the distinction between separate storage systems stems from findings suggesting differences in capacity and speed of processing between the two structures. Short Term Memory has a limited storage capacity and a relatively rapid input and retrieval, in contrast to Long Term Memory, which has an enormous capacity but is slower to register information, and the information is more slowly retrieved from it.

Arguments for the limited capacity of Short Term Memory come primarily from tasks such as digit span. Miller's (1956) classic paper, *The magic number seven*, revealed that there was a limited Short Term Memory span of about seven plus or minus two

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[7] In further defence of using recency as a support for a separate Short Term Memory system, it is worth briefly discussing two findings by Baddeley and Hitch (1977) that are often quoted as evidence against a Short Term Memory account of recency. They found that performing articulatory suppression (e.g. saying "the, the, the") or carrying out a span task while reading a list did not wipe out the recency effect. As Pashler and Carrier (1996) point out, articulatory suppression may not fully suppress articulation and so may leave some of Short Term Memory free for encoding which in turn produces a recency effect in free recall. Their proof of this inadequacy of articulatory suppression is that if one performs articulatory suppression whilst reading a list of words, it is still possible to make rhyming judgements. In terms of the span task, Pashler and Carrier (1996) are quick to mention that the span list was presented in a different modality to the word list and as discussed later, could have allowed the recency items to inhabit a different Short Term Memory subsystem to the subsystem involved in the span component of the task. A more elegant explanation for this finding is explicitly addressed by Della Salla and Logie (1993), and it will be mentioned later in the discussion of the Baddeley and Hitch (1977) finding in section 1.3.2.3.

alternative chunks of information. Similarly, the recency effect in free recall is typically limited to about three items (Craik, 1971), as if constrained by a limited capacity.

Evidence that the input of data to Short Term Memory is rapid is supported by Murdock (1965). In his study, subjects sorted a deck of cards based on colour, suit, or by the properties of a card's number, at the same time as they heard a series of words for subsequent free recall. As a variable, Murdock varied the complexity of the categories into which the cards were to be sorted. The results of the study indicated that the greater the sorting load, the poorer the performance of subjects for all except the most recent items. The implication is that when receiving input into the Short Term Memory system, less attention is demanded than is necessary for long term learning.

Evidence for the rapid retrieval from Short Term Memory was provided by Waugh (1970), using the digit probe task. In the digit probe task, subjects are presented with a sequence of 15 or 20 numbers, or other items. The sequence is followed by a probe item taken from the sequence and subjects must say which item followed the probe. Waugh (1970) noted that not only were more recent items more likely to be correct, but also that correct items from the recency portion of the curve were produced more rapidly than correct items from the earlier primacy component. The implication being, that the most recent items were stored in Short Term Memory, and that their retrieval from there was faster than for the items stored in Long Term Memory.

1.2.2.3 Evaluating Early Models of Short Term Memory

The models of Short Term Memory that I have mentioned in section 1.2.1.1 are supported to the extent that there is a separable Short Term Memory component. However certain aspects of the data actually go against the specifics of these models, and other evidence also raises problems with them. I will now discuss the problems with these models that are raised by the data.

The major limitations of Broadbent's (1958) and Waugh and Norman's (1965) models were that these models only really dealt with verbal rehearsal and storage, and failed to specify alternative strategies for coding and retrieval. Atkinson and Shiffrin's (1968) model therefore aimed to revise and extend these models, and to this end, most criticisms of the Modal Model (see below in section 1.2.2.4) would also apply to these other two models.

In terms of Production-Systems models, although they did pay attention to control processes, they were only really capable of simulating human behaviour if the number of "slots" available was increased far beyond any reasonable estimate of the immediate memory span (Rumelhart and Norman, 1983). For example, Ohlsson (1987) advanced a Production-System model of logical reasoning that incorporated a Short Term Memory of about 75 elements. Although the initiative for having slots in these systems emanated from the idea of chunking set forth by Miller (1956), subsequent research has suggested that chunking and other devices for enhancing memory performance actually enriches the organisational structure of Long Term Memory rather than that of Short Term Memory (Ericsson and Pennington, 1993).

1.2.2.4 Problems with the Modal Model

1. Neuropsychology

A major problem with the Modal Model stemmed from the neuropsychological evidence. If the Short Term Store was a crucial system that is necessary for long term learning, then why should some patients with massive Short Term Memory impairments nonetheless show normal long term learning? According to the Modal Model, the reduced auditory memory span of the patient with intact long-term learning ability (Shallice and Warrington, 1970) presents such a contradiction.

2. Transfer to Long Term Memory

A second problem for the Modal Model concerned its assumption that the probability that an item will be transferred to the Long Term Store will be a direct function of its time of maintenance in the Short Term Store. Tulving (1966) asked his subjects to repeatedly read through a list of words which were then included in a larger subsequent list which subjects had to study. There was no indication that the previous repetitions had enhanced subsequent learning: simply repeating the words did not increase their accessibility, whereas active subsequent learning did. Similarly, Morton (1967) demonstrated that when subjects were asked to reproduce the pattern of numbers and letters on the British telephone dial, they were unable to do so. Here was another example of how repeated exposure does not ensure entry into the Long Term Store.

3. Recency Effect

Regarding the recency effect, the Modal Model offers a simple and straightforward account, by assuming that it represents the immediate output of those items currently held in the Short Term Store. This would account for the lack of recency in free recall tasks for patients with an impaired Short Term span, and for normal subjects who have done a distracter task before test. However, the results of the Baddeley and Hitch (1977) study (mentioned in the footnote to section 1.2.2.2), where recency remains despite a concurrent digit span task, questions the Modal Model's explanation. Both span and recency should have competed for the same limited capacity Short Term Store.

4. Retrieval from Long Term Memory

Further evidence from dual-task methodology questioned the assumption of the Modal Model that the Short Term Store was responsible for retrieval from Long Term Memory as well as for storage. Baddeley, Lewis, Eldridge and Thomson (1984) found that a concurrent task (such as digit span or articulatory suppression) during the retrieval of a list of 32 words that subjects had previously learned, had no effect on the accuracy of performance. If the Short Term Store was involved in retrieval, surely it should have been pre-occupied with storing digits, and therefore be unable to retrieve the words from Long Term Memory.

5. More Dual-task Methodology

In a similar vein, more data from Baddeley and Hitch (1974) presented problems for the Modal Model. These authors tried to disrupt the operation of the Short Term Store by requiring subjects to remember sequences of up to six digits at the same time as they performed each of a range of Short Term Store tasks. In one study, they presented subjects with sequences of 16 unrelated words for free recall. Subjects heard the words and were simultaneously presented visually with groups of nought, three, or six digits, which they were required to recall immediately after the end of the free recall of the word list. In another study, words were presented visually and the digits in an auditory modality.

Predictions from the Modal Model on the performance on the words are clear - the digit span task should depend on the Short Term Store, with three digits using up a substantial amount of it's resources and six digits being near span, virtually wiping it out. This in turn, should lead to a substantial impairment in performance on recall of the primacy items of the word lists (as transfer to Long Term Memory would be blocked), and to a total abolition of the recency effect (as the Short Term Store would be otherwise engaged). The obtained results went against these predictions. Three digits caused no significant impairment, whereas six digits led to a moderate but significant impairment in the primacy part of the curve, but did not impair the recency component.

6. Visuospatial Short Term Memory

Finally, evidence from Baddeley, Grant, Wight and Thomson (1975b) raises difficulties with the Modal Model. The Modal Model is able to deal with their finding that tracking a spot of light causes a marked impairment when subjects concurrently perform a visuospatial task. This is because, according to the Modal Model, their limited capacity Short Term Stores cannot cope with both tasks. However, what is puzzling according to this interpretation is that when their subjects' Short Term Stores were engaged once again in the tracking task, they were now successful at concurrently performing a rote verbal memory task.

1.2.3 Levels of Processing as an Alternative to the Modal Model

As problems with the Modal Model began to accumulate, interest in Short Term Memory declined because many of the main researchers in the area moved into other areas (Baddeley 1990). The field seemed to be becoming increasingly fragmented with an excess of techniques and of individual models, but a lack of any overall generally agreed framework.

The Modal Model had been an essentially structural model: it did have functional components such as control processes and encoding activities, but these were conceptually less important than the overall structural architecture. Craik and Lockhart's (1972) influential paper on Levels of Processing reversed this emphasis by playing-down structure and in stressing processing, suggesting that trace durability was a direct consequence of the processes of encoding, with deeper and more elaborate encoding leading to more durable memory traces.

The attack of the Levels of Processing framework on the Modal Model was targeted mainly at the learning assumption made by the Modal Model. As mentioned above, studies showed that long-term learning did not necessarily involve transfer from the Short Term Store and the probability of transfer was not necessarily proportional to the time information spent in the Short Term Store (Craik and Watkins, 1973).

The Levels of Processing framework absorbed much of the research effort that had previously been directed to understanding Short Term Memory (Baddeley, 1990). In some cases the familiar argument emerged that the new framework obviated the need for a concept such as Short Term Memory (Postman, 1975). However, Craik and Lockhart themselves continued to assume a Short Term or Primary Memory System that played an important part in the process of encoding and recoding. Although the theoretical power of Levels of Processing has been questioned (e.g. Baddeley, 1978), it remains a useful broad framework that ties together a good deal of evidence on the relationship between coding and Long Term Memory (e.g. Hyde and Jenkins, 1969; Craik and Simon, 1979).

At the same time as Craik and Lockhart were developing and elaborating their approach, Baddeley and Hitch were attempting to tackle the problem of developing an adequate model of Short Term Memory from a somewhat different viewpoint (Baddeley and Hitch, 1974). In particular, they were concerned with the question of whether Short

Term Memory acted as a "Working Memory". The term Working Memory implies a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks, such as comprehension, learning and reasoning. The model successfully takes into account much of the traditional Short Term Memory data as a separate Short Term Memory system that faces capacity limitations.

1.3 Working Memory

1.3.1 Overview of the Model: Fractionating Short Term Memory

Although Atkinson and Shiffrin (1968) had previously raised the possibility that Short Term Memory was not unitary, Baddeley and Hitch (1974) proposed that the concept of a unitary Short Term Memory system be completely abandoned, and replaced by a tripartite system. Baddeley and Hitch's model assumes the attentional controller, the *Central Executive,* aided by two "slave systems", each of which being able to actively maintain information of a particular kind. The *Visuospatial Sketchpad*[7] is assumed to hold and manipulate information about objects and locations, while the *Phonological Loop* is a system that is assumed to be capable of storing and manipulating speech-based information. Digit span is assumed to depend principally on this latter system, although executive processes will be required to maintain the operation of the Phonological Loop when task demands are sufficiently high (Hitch and Baddeley, 1976). Similarly, the involvement of the Central Executive in Visuospatial Sketchpad functioning would also hold for equally demanding visuospatial tasks.

Note that with this analysis, even when a subject is performing at the limit of span, this does not necessarily imply that executive processes are fully stretched. According to the model, the level of performance on a task such as digit span (which involves minimal complex processing) will be determined by storage limitations in the Phonological Loop, with the result that subjects who are performing at the limits of digit span will still have executive capacity left over for performing other tasks such as reasoning and comprehension. It is also important to realise that this part of the system deals with Long Term Memory, and that these activities are independent of storage in the slave systems.

[7] Although originally labelled the Visuospatial*Scratch*-pad, Baddeley (1986) states that "Visuospatial Sketchpad" is the preferred term for this component of Working Memory. This is because, according to Baddeley, "Visuospatial Sketchpad" denotes storage of purely visual shapes, whereas Visuospatial Scratchpad may suggest verbal notes as much as it does visual shapes.

The Phonological Loop itself consists of two components: a passive Phonological Store and an Articulatory Rehearsal Process [8]. Information gains access to the Phonological Store either directly, via auditory presentation of speech stimuli, or indirectly, via internally generated phonological codes for non-auditory inputs such as printed words or familiar objects. Phonological representations of memory items decay rapidly in the Phonological Store within two seconds, if unrehearsed (Baddeley, Thomson and Buchanaan, 1975a). Subvocal rehearsal occurs serially and in real time, and acts to refresh decaying representations in the Phonological Store.

The Visuospatial Sketchpad's architecture is not as clear-cut as the Phonological Loop, and one option is that it is a unitary sub-system with separable dimensions for visual and spatial information (Baddeley, 1996). Another possibility is that it has two primary subcomponents like the Phonological Loop (Logie, 1994). According to this formulation, there is a Visual Store in which the physical characteristics of objects and events can be represented, and a spatial mechanism that can be used for planning movements and that may also serve a rehearsal function by reactivating the contents of the visual store. The evidence for the Visuospatial Sketchpad's architecture will be soon be examined.

1.3.2 New Solutions to Old Problems

The problems that were raised with the Modal Model are solved with the Working Memory model, as outlined below.

1.3.2.1 Neuropsychology

The patients with impaired Short Term Memory performance (Shallice and Warrington, 1970) whose deficit posed problems to the earlier models of Short Term Memory, are explained very neatly by this model. The reason why these patients could function relatively well in other cognitive domains could not have been because their whole Short Term Memory Systems were impaired. Rather, their performance on the digit span tasks reflected a local impairment of their Phonological Loop. This however, will not have prevented the Central Executive or the Sketchpad being used by these patients for long term learning and general information processing.

1.3.2.2 Transfer to Long Term Memory

With the Working Memory Model, there is no need to assume that by simply having information entering Short Term Memory, there will be transfer to Long Term Memory, as there was in the Modal Model. Recall (from section 1.2.2.4) the evidence which

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[8] Also termed here the "Articulatory Control Process".

showed that repeated exposure does not ensure entry to Long Term Memory posed a problem for the Modal Model. With the fractionation of Short Term Memory, information can just be stored in a slave system and maintained, and at the discretion of the Central Executive, transfer to Long Term Memory is possible.

1.3.2.3 Recency Effect

Because span and recency should compete for the same limited capacity Short Term Store, the fact that recency remains despite a concurrent digit span task (Baddeley and Hitch, 1977) questioned the Modal Model's explanation. Della Sala and Logie (1993) suggest that recency is attributable to the Phonological Store, and that span tasks are attributable to the Articulatory Rehearsal Process. They cite evidence for this including neuropsychological evidence of a double dissociation between recency and span (Capitani, Della Sala, Logie and Spinnler,1992), and further evidence that errors in recency are phonologically based (Shallice, 1975) whereas span tasks are affected by articulatory suppression.

1.3.2.4 Retrieval from Long Term Memory

Baddeley et al. (1984) found that subjects were able to retrieve from Long Term Memory at the same time as engaging their Short Term Memory in a concurrent digit span task. Recall that the Modal Model would not have predicted this, since the Short Term Store is both responsible for retrieval from Long Term Memory and short term storage. Clearly the Working Memory model has no problem with this, as the Central Executive can retrieve from Long Term Memory independently to the activities of the Phonological Loop, as long as output does not heavily involve the Phonological Loop.

1.3.2.5 Dual-task Methodology

The Modal Model made firm predictions in Baddeley and Hitch's (1974) study where the load of a digit span task was systematically varied as subjects concurrently engaged in learning word lists. Because it contained a unitary Short Term Store, with a load of three digits there should have been some interference on performance in the list learning task, and with six digits, deleterious consequences. However, the results that three digits caused no significant impairment and six digits only a moderate impairment, questions whether the two tasks are sharing the same unitary Short Term Store. The Working Memory Model allows concurrent processing by the Central Executive during a dual-task, and thus list learning (and other more complex tasks) can benefit from executive resources. Furthermore, if a slave system is not pushed to capacity, the Central Executive will have plenty of free resources and performance will remain relatively unimpaired.

1.3.2.6 Visuospatial Short Term Memory

The fact that two concurrent visual tasks interfere with one another, but that a concurrent visual and verbal task do not impede each other's performance (Baddeley, et al., 1975b) is perplexing for the Modal Model. However, given the separate slave sub-systems that specialise in the storage of the two modalities of information in this study, the Working Memory Model can explain the effect. The interference observed when there are two visual tasks is due to the fact that information from both tasks are competing for the Visuospatial Sketchpad. However, when one task is verbal and the other visual, the Phonological Loop and the Visuospatial Sketchpad can independently store the relevant information, preventing interference between the concurrent activities.

1.3.3 The Components of Working Memory

1.3.3.1 Introduction

Now that the Working Memory Model has been presented as a viable model of Short Term Memory, I will discuss each of its components in turn. It should be noted though, that by far the greatest amount of research has been directed at understanding the Phonological Loop. However, because my empirical work deals with an ostensibly visuospatial task, I will examine the Visuospatial Sketchpad in the greatest detail.

1.3.3.2 The Central Executive

1. The Supervisory Attentional System

The Central Executive is the most complex and least understood component of the Working Memory Model. Initially, the Central Executive was neglected in favour of tackling the more tractable slave systems. More recently though, it has been specified in a little more detail, incorporating the Norman and Shallice (1980) model of the attentional control of action (Baddeley, 1986). Norman and Shallice assume that routine activity is controlled by means of a series of over-learned schemata whereby past experience interacts with environmental cues and prompts. When two schemata require action that is inconsistent, then conflict-resolution procedures come into operation so as to allow the schema with the highest priority to gain precedence. However, when novel situations arise, either in emergency or through encountering situations that are non-routine, a second system comes into operation, the Supervisory Attentional System. This system operates by changing the probabilities of actions so as to allow the existing schema to be overridden.

Slips of action are explained on the basis of the triggering of inappropriate schemata. For example, setting off to drive somewhere, but finding that one automatically drives to work instead. The routes may have a common start, and if the Supervisory Attentional System is occupying itself with other matters, a more frequent work-driving plan takes over.

Patients with frontal lobe damage tend to show a strange combinations of distractibility (Shallice, Burgess, Schon, and Baxter, 1989) and perseveration (Baddeley and Wilson, 1986). The distractibility is illustrated by the phenomenon of utilisation of behaviour, in which the patients will respond, often inappropriately, by manipulating any object that comes to hand. So if there is a glass on the table they tend to pick it up and drink from it, and if there is a pen there they will write with it, and so on. Perseveration occurs when the subject appears to have great difficulty in breaking away from a given pattern of responding. An example would be where a patient appears to be stuck in a loop of repeating an aspect of a story that they are telling.

Shallice suggests that patients with frontal lobe damage have a deficit in the operation of the Supervisory Attentional System, which results in difficulty in the attentional control of action. Utilisation behaviour occurs because the system is captured by any triggering stimulus that occurs in the absence of long-term Supervisory Attentional System control. In a situation where there are many stimuli, a succession of different schemata are triggered. Perserveration occurs when one schema dominates, and captures the attentional system. In its original formulation, two separate subprocesses are proposed for routine and novel actions. Later formulations stress that both processes can occur together, but routine tasks rely more on schema based control processes, whereas new tasks place heavier demands on the Supervisory Attentional System (Shallice and Burgess, 1993)

2. Random Generation

It was thus proposed that the Central Executive operated in broadly the same way as Norman and Shallice's Supervisory Attentional System (Baddeley, 1986). Adoption of the model provided an explanation of an otherwise puzzling phenomenon, namely the limited capacity for 'random generation'. If subjects are asked to produce a stream of random letters at rate of one per second, they rapidly find that they are deviating from randomness and producing sequences that follow the alphabetic stereotype (e.g. PQR), or generating common acronyms such as USA and BBC. The effect is not due to a false concept of randomness, as it disappears if subjects are allowed to respond more slowly. It appears to be linked to available attentional resources, as randomness declines systematically with speed of generation. It is also lawfully related to the demands of a concurrent task such as choice reaction time.

The pattern of results can be explained with the assumption that the selected task requires the rapid selection of responses, while avoiding the stereotypy that would be produced by existing habits. The greater the capacity of the Supervisory Attentional System, or the more the available time, the better the chance of selecting a novel response and avoiding a stereotyped letter, or the repetition of items that are readily available because recently used.

If random generation is dependent in this way on the Supervisory Attentional System, then it should prove a powerful way of disrupting the operation of the Central Executive. In a range of studies on the role of Working Memory in chess, random generation has proved to be a particularly potent way of disrupting performance, whereas articulating a predictable stream of spoken items at the same rate has no effect (Robbins, Anderson, Barker, Bradley, Fearnyhough, Henson, Hudson and Baddeley, 1996). The effectiveness of random generation does not depend on using letters or, indeed on verbal output. Baddeley (1993) reports the details of a study which explores a task in which subjects are required to attempt to generate random key presses. This condition is contrasted to one in which the keys were pressed in a systematic order. Degree of randomness is substantially disrupted by a range of tasks that would be expected to depend on the functioning of the Central Executive, ranging from problem solving to generating items from semantic categories.

3. Role of the Central Executive

A prime feature of the function of the Central Executive is to co-ordinate information from a number of different sources. Baddeley and colleagues have tried to use this assumption in designing tests that aim to elucidate the role of the Central Executive in Alzheimer's disease (Baddeley, Logie, Bressi, Della Sala, and Spinnler, 1986). Earlier studies had suggested the possibility of an executive deficit in this disease, and this was explored by choosing two tasks that loaded separately on the Visuospatial Sketchpad and Phonological Loop, adjusting the level of performance on each so that the patients were functioning at a similar error rate to the controls. The two tasks were then combined in true dual-task methodology style. Normal elderly subjects are no more disrupted by the requirement to combine the two sources of information than are young subjects, provided the level of difficulty is matched. On the other hand, Alzheimer patients are markedly impaired, with the degree of dual-task disruption increasing systematically as the disease progresses, in contrast to their relatively stable performance on the individual component measures.

1.3.3.3 The Phonological Loop

1. Phonological Store

Much of the early work on Short Term Memory focused on the storage of verbal information, and these studies can be understood to involve Working Memory's Phonological Loop component. Evidence on the nature of the Phonological Store comes principally from two phenomena. The first is the phonological similarity effect, whereby similar sounding items such as the letters *p g v c t* are harder to remember accurately than a dissimilar sequence such as *k y r w s* (Conrad and Hull, 1964). This is assumed to occur because the items are stored in terms of a phonological or a speech-based code; as the items fade, the similar items have fewer distinguishing features and hence are more subject to error.

A second phenomenon that supports the concept of the Phonological Store is the irrelevant speech effect (Colle and Welsh, 1976). If a subject is trying to remember a sequence of visually presented numbers, then performance will be disrupted by the presence of simultaneous irrelevant spoken material. The disrupting effect is just as strong if the irrelevant material comprises nonsense as when it contains real words. Even other digits cause little additional problems over and above that of any other spoken items. The irrelevant speech effect does not appear to reflect simple distraction either, as bursts of white noise have no effect on performance, and neither does the intensity of the irrelevant stimulus, provided that it is clearly audible (Salamé and Baddeley, 1982). The effect is explained by the Working Memory model by assuming that spoken material gains obligatory access to the Phonological Store, where it is able to corrupt the memory trace[9].

2. Articulatory Control Processes

Characteristics of the Articulatory Control Process are indicated by two phenomena, the word length effect and the effects of articulatory suppression. If a subject's memory span for words is measured, then it becomes clear that span for long words such as *opportunity, individual,* and *university,* is substantially less than that for short words

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[9] It should be noted however, that Jones (1994) has suggested an alternative explanation for the effect. According to Jones, the effect of irrelevant speech in the serial recall of visually presented verbal sequences can be produced with non-speech material such as tones that vary from moment to moment. In contrast to this, invariant non-speech stimuli do not result in any disruption of serial recall. Jones contends that the irrelevant speech effect can be understood by supposing that the recall of order information is disrupted by any auditory stream that changes state, and that it is not specifically a speech-based phenomenon. Nevertheless, what should become clear form the evidence reviewed in this chapter, is that the specified nature of the components of Working Memory does not depend on the

such as *sum, harm,* and *wit* (Baddeley, et al., 1975a). This is what is termed as the word length effect. Indeed, memory span is linearly related to the spoken duration of the constituent items. This leads to consistent differences in digit span across different languages, dependent on how long digits take to articulate in that language (Ellis and Henelly, 1980). In addition to this, the development of digit span over childhood parallels an increase in articulation rate, suggesting that much of the increase may be due to the capacity of the child to rehearse more rapidly (Hitch, Halliday, and Littler, 1984). I shall return to this briefly in the next chapter in section 2.2.3.1, during my review of Working Memory development.

Baddeley et al. (1975a) propose that the word length effect occurs because subjects maintain the memory trace by recycling the items, with span being set by the joint function of the rate of decay of the trace and the speed with which it can be refreshed by rehearsal. As rehearsal occurs in real time according to the model, long words are rehearsed more slowly, allowing more forgetting and hence leading to a reduced span. However, a major part of the word length effect may arise from the delay in recall due to longer time taken to produce the 'long word" sequences at recall (Cowan Saults, Keller, Johnson, and Flores, 1992). I will describe some studies that demonstrate this, at the end of the chapter (in section 1.3.4.1).

If subjects are prevented from rehearsing the material to be remembered, by the requirement to repeatedly utter some irrelevant sound such as the word *the*, then performance is impaired (Murray, 1968). This is termed articulatory suppression. Overt articulatory suppression, of course, does lead to the creation of irrelevant speech, and so it could be argued that the two effects are confounded. However, Gupta and Macwhinnie (1995) have shown that suppression has a powerful effect that is over and above any influence of irrelevant speech. Suppression also removes the word length effect, provided it occurs during both input and written recall (Baddeley, Lewis and Vallar, 1984). If the subject is not subvocally rehearsing, then it does not matter how long the words are, indicating that articulatory suppression and the word length effect emanate from the same source, namely the Articulatory Rehearsal Process.

Articulatory suppression also interferes with the phonological recoding of visually presented materials. Thus, the phonological similarity effect occurs with visual or auditory presentation. But when a subject is required to suppress articulation, then phonological similarity has no influence on visual presentation, although it continues to

irrelevant speech effect alone. The full implications of Jones's results for the current model of Working Memory remain to be explored.

have an effect when presentation is auditory (Baddeley et al., 1984). If the stimuli used are such that the subject cannot name the visually presented material, then it must be stored in some non-phonological code. With auditory presentation, direct phonological representation is guaranteed however, without the need to recode through articulation.

3. Neuropsychology of the Phonological Loop

The simple Phonological Loop model offers a clear interpretation of the patients with defective Short Term Memory performance (see section 1.2.2.2). Such patients typically show reduced memory span, and this is particularly with auditory presentation. With visual presentation, they typically show no evidence of phonological similarity and no word length effect (Vallar and Shallice, 1990). The Working Memory model says that these patients have an impairment in the Phonological Loop system, which may reflect either a defective store (Vallar and Baddeley, 1984), or in other cases a defective operation of the articulatory control process, usually in association with dyspraxia[10] (Caplan, Rochon, and Waters, 1992).

4. Role of the Phonological Loop

As I have just indicated, the previously described Short Term Memory deficit patients appear to have a deficit in the Phonological Loop system (Vallar and Shallice, 1990). The assumption has been made that they presumably do not suffer the general cognitive disturbance that would be predicted by the Modal Model, because they have preserved Central Executive and Visuospatial Sketchpad functioning. On the other hand, the fact that such patients appear to have so few problems in coping with everyday life, raises the question of the function served by the Phonological Loop.

A clue to answering this question was given by a study (Baddeley, Papagno, and Vallar, 1988), in which a patient with a very pure phonological memory deficit was required to learn either pairs of words in her native language *(e.g house-dog)* or the Russian equivalent of familiar words *(e.g. rose-svieti)*. She proved to be normal at standard paired associates learning, but was very poor at new phonological learning. Later studies (Papagno, Valentine, and Baddeley, 1991) have attempted to simulate this using articulatory suppression with normal subjects, and have shown that whereas paired associate learning is unaffected by suppression, foreign language vocabulary learning is clearly impaired.

This idea will be touched upon again in the next chapter (section 2.2.3.1), when I review the developmental literature on the Phonological Loop. The basic evidence

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[10] This is a condition characterised by painful movement and difficulty in moving.

seems to be consistent with the hypothesis that the Phonological Loop has evolved, probably from more basic auditory perception and verbal production mechanisms, as a device for language acquisition. Impaired functioning of the Phonological Loop is therefore likely to be much more troublesome for a child, who is just learning language and related skills such as reading, than it is for an adult. Hence the Short Term Memory deficit in adult patients' cognitive functions are relatively spared only because they have already acquired language in their youth.

1.3.3.4 The Visuospatial Sketchpad

1. Experimental Dissociations

I have already mentioned (in section 1.3.2.6) the dual-task study by Baddeley et al. (1975b) which demonstrated the independence of visual and verbal Short Term Memory. This is just one of a few pieces of evidence that displays the severely disruptive effects of concurrent visual tasks on other visual tasks, but not on verbal tasks. Recall that Baddeley et al (1975b) used a task that required retention of visuospatial images in conjunction with a visual tracking task for "disruption", and the tracking task with a concurrent rote verbal memory task for "no disruption". Baddeley, Bressi, Della Sala, Logie and Spinnler (1986), for example, demonstrated a further lack of disruption using a standard digit span task together with a visuospatial tracking task.

Other demonstrations of this type include Farmer, Berman and Fletcher's (1986) study, where articulatory suppression impaired performance on a reasoning test, but had no effect on the performance of a visuospatial manipulation test, known as the Manikin test (Benson and Gedye, 1963). In the same experiment, Farmer et al. (1986) showed that concurrent arm movement disrupted performance on the Manikin test, but had no effect on the reasoning task. The interpretation given in by the authors in these findings is that both arm movement and visuospatial processing share a cognitive resource that is not required for articulatory suppression, nor for the verbal reasoning test. The latter two tasks thus involve the Phonological Loop, a verbal cognitive resource that is quite different to that used in the visuospatial tasks. Finally, Logie, Zucco and Baddeley, (1990) established that concurrent arithmetic dramatically impairs retention of a visually presented letter sequence, but has negligible effects on the retention of a visual matrix pattern. Conversely, a concurrent visuospatial imagery construction task interferes with retention of the matrix pattern, but has very little effect on memory for a random letter sequence.

2. Neuropsychological Dissociations

Data from neuropsychological patients, can also be used to dissociate verbal and visuospatial Short Term Memory. This comes from the report of patients with verbal Short Term Memory deficits, who perform within the normal range on tests of visual and spatial processing. For example, patient KF (Shallice and Warrington, 1970) had an auditory digit span of two items, but a visual presentation span of four items. Moreover, his errors in recall of visually presented letters tended to be based on visual confusions rather than on phonological confusions (Warrington and Shallice, 1972). The implication being that he was able to use his Visuospatial Sketchpad, but had suffered damage to his Phonological Loop. Saffran and Marin (1975) describe a patient IL, who had an auditory digit span of 2.9 and a visual digit span greater than 5. These patterns are contrary to those found in normal adult subjects where auditory digit span is typically superior to visual digit span (Conrad, 1964). Once again, IL provides evidence of someone who was not able to use the Phonological Loop, but was able to use the Visuospatial Sketchpad.

There are also patients who appear to have visual and/or spatial Short Term Memory deficits, but who perform within the normal range for verbal Short Term Memory tasks. De Renzi and Nichelli (1975) document two cases of right hemisphere brain-damaged patients with pathologically poor performance on the Corsi span task[11] (score of 2.5), compared with performance well within the normal range on the digit span and digit pointing (scores between 6.5 and 7.5).

3. Localisation within the Brain

At a general level, it appears that the right hemisphere is more important in processing information that would be handled by a visuospatial memory system (de Renzi and Nichelli, 1975). Cortical excisions for temporal cortical epilepsy on the right hand-side impair spatial memory, but do not hamper verbal Short Term Memory (Corkin, 1965). A more specific role of the hippocampus has been shown in man (Petrides, 1985), and confirmed in animal studies (Olton, Becker and Handelman, 1979). In these studies, the authors go so far as to implicate the area of CA3 of the hippocampus, where the so-called "place cells" are probably located. However, this assumption is still somewhat controversial (Jarrard, 1993).

[11] This is Corsi's block tapping test, in which the subject is presented with an array of nine blocks scattered in a quasi-random manner (Milner, 1971). The experimenter taps a sequence of blocks, and the subject attempts to imitate the sequence. As with digit span, performance is measured by the longest sequence that can successfully be replicated, and is usually about two items less than digit span.

The most frequent lesions noted in patients presenting visuospatial memory deficits are in the posterior part of the right hemisphere, namely the posterior parietal lobe near its junction with the occipital lobe (Warrington and James, 1967). This is significant since this localisation is not only different from that proposed for the Phonological Loop and global amnesia, but also from the site implicated in processing visually presented verbal material (Kinsbourne and Warrington, 1962).

4. Architecture of the Visuospatial Sketchpad

The model for the Phonological Loop that was discussed above emerged due to the accumulation of a large body of evidence, which in turn produced a framework within which theoretical questions could be asked and explored experimentally. However, the relative lack of evidence on the Visuospatial Sketchpad has been accompanied by a lack of an explicit model or framework for studying visuospatial Working Memory.

The basic function of the Visuospatial Sketchpad must be some means by which information gets into the memory system from the senses or from longer term storage. Given that it holds information on a temporary basis, the system must be subject to a process by which information may be lost over time, whether through decay of the memory trace or through interference from new material. Such a system must have some means to extend the retention of a particular material should this be necessary. Finally, given that it is a system that purports to store or manipulate visual and/or spatial material, the memory code involved should have some relationship with the characteristics of the visual and spatial material with which the system has to deal. These are general requirements of any temporary memory system, and probably strike a chord with the structure of the Phonological Loop. This is no coincidence. It will become clear that the attempt to model the Visuospatial Sketchpad takes the Phonological Loop's structure as the starting point.

Recall that one of the recurring themes in the discussion of the Phonological Loop was that there appeared to be an overlap between the speech system and verbal short term storage (ie. phonological similarity effect and word length effect). The search for a parallel overlap between the visuo-perceptual system and the Visuospatial Sketchpad in the Visuospatial Sketchpad will be examined in four different ways. Firstly, through a careful analysis of the relationship between visual imagery and visual short term storage. Secondly, investigating whether visual and spatial information are dealt with in the same way by the Visuospatial Sketchpad. Thirdly, examining whether visual similarity of stimuli will result in confusions in memory. Finally, I shall briefly examine whether there are visual recency effects, since the verbal recency effect had such an impact on research of models of Short Term Memory.

a. Visual Imagery

A theme in studying the link between visual Working Memory and visual imagery has been to investigate effects for highly imageable material. One well established finding is that concrete words are easier to recall than abstract words. Paivio (1971) has suggested that this is due to the possibility of dual coding with concrete words. That is, concrete words can be coded in terms of the attributes of the word, such as its sound, length and so on. It can also be remembered in the form of a visual image of the class of objects named by the words (e.g. table, dog). On the other hand, abstract words are very difficult to image in this way and just generate a verbal code. The availability of two codes for concrete words, according to Paivio, leads to an advantage in recall for this material.

Baddeley et al. (1975b) set out to explore whether the temporary visuospatial processing and storage system is involved in the appearance of the recall advantage for concrete words. At first sight it appears that Paivio's verbal code could be associated with the Phonological Loop and his visual code could be reinterpreted as visuospatial Working Memory. The retention of information may therefore be better when the representation includes material held in both the Phonological Loop and in the visual and spatial stores. They reasoned that if concrete words were recalled better for this reason, then concurrent visuospatial processing should undermine this advantage. The hypothesis was tested by trying to induce interference with a concurrent pursuit visual tracking task, but there was no such disruption. This lead them to the conclusion that the concrete-abstract difference was due to the richness of semantic associations for concrete words rather than the use of visual imagery. This conclusion has received further support from the work of Jones (1988) who showed that the concreteness effect was highly correlated with the ease with which subjects could generate predicates of the words or specify ways in which the word could be used[12].

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[12] It may be important to first consider the difference in approach between the visual imagery theorists' (e.g. Kosslyn, 1991) idea of a 'Visual Buffer', involved in manipulating visual images, and the concept of the Visuospatial Sketchpad in the Working Memory literature. This difference can be summarised as follows. In the Working Memory literature, there is an explicit involvement of the Visuospatial Sketchpad in a collection of systems involved in temporary storage and processing. The Visual Buffer, however, has been regarded largely in the context of its relationship with long term visual memory and with visual perception. Different tasks and techniques have been used by the two literatures, and it is uncertain whether the same mechanisms are involved in both sets of tasks. For example, in the Working Memory literature, there is considerable emphasis on temporary storage of visual and spatial information. In the imagery literature, there is an emphasis on the generation and manipulation of visual images. This could be put better by saying that a combination of the Visuospatial Sketchpad and the Central Executive of Working Memory *could* incorporate some of the processes and concepts in imagery research. Baddeley (1986) has suggested that an imagery task with a relatively precise spatial component (like the Brooks matrix task - see main text in this section), is more likely to place huge demands on the Visuospatial Sketchpad, as it requires accurate maintenance and rehearsal, whereas a task such as a peg word mnemonic (see also this section), will allow considerable "spatial flexibility".

From the perspective of Working Memory, a more fruitful approach stemmed from the work of Brooks (1968). In one of his studies, Brooks asked subjects to perform either a visual imagery task or a verbal task. The imagery task involved asking subjects to imagine a 4 x 4 arrangement of squares, which was followed by a sequence of sentences describing a path around the squares, and the described path could easily be retained by means of visual imagery. Work by Brooks revealed that the spatial sequences are better retained when presented auditorily, rather than visually. Brooks interpreted his results to mean that the representation of the visual pattern evoked by the spatial sequences relies on a visuospatial coding system that mutually interferes with the visual processing of written material.

Baddeley et al. (1975b) combined the Brooks' task with a concurrent tracking task. They found that recall of the imageable sequence was disrupted by concurrent tracking, but tracking had no effect on recall of equivalent verbal sequences which could be retained only by verbal rehearsal. In a follow-up study, Baddeley and Lieberman (1980) demonstrated that the Brooks' matrix task was also disrupted by a tracking task that was spatial but not visual. This was achieved by having the subject point to a moving sound source. Retention of the matrix was not affected by a concurrent purely visual task, in which subjects made judgements about the brightness of a field of light. This pattern of results led Baddeley and Lieberman to suggest that the Visuospatial Sketchpad was indeed a system that was involved in visuospatial retention, and in visuospatial perception and motor control. They also concluded that the system was most likely to be a spatial system rather than a purely visual or a visuospatial one.

These conclusions were challenged by Logie (1986). He suggested that Baddeley and Lieberman's results could not be generalised on the basis of a single task. Logie used a paired-associate learning paradigm, instead of the Brooks task, in which subjects under one condition were encouraged to use a pegword mnemonic. This involved learning rhyming imageable pegwords for each digit from 1 to 10 and forming an image of the pegword interacting with the items to be remembered. Performance was compared with a condition in which the use of imagery was minimised by instruction and by rapid presentation. Logie discovered that a range of visual, but relatively non-spatial tasks, would interfere specifically with the use of a mnemonic. While the strongest disruption occurred when the subjects passively observed line drawings, significant impairment

(Baddeley goes on to concede that the non-spatial characteristics of visual imagery present themselves as a puzzling question). Given these differences, both in the theoretical concepts and techniques used, there is considerable ambiguity as to whether the two literatures are studying the same phenomena or functional mechanism. For these reasons, since this chapter is concerned with Working Memory, I was found even when material that was as non-spatial as patches of colour were used. The effect of irrelevant patterns appears to be analogous to the effect of irrelevant speech on the Phonological Loop.

Taken together, these studies establish that the Visuospatial Sketchpad is associated with both highly visual and highly spatial imagery tasks. Perhaps more interestingly, it has brought up the issue of the characteristics of the Visuospatial Sketchpad. It raises the possibility that the Visuospatial Sketchpad itself may be fractionated into separate visual and spatial components. I now turn to this issue which centres around the essential nature of the Visuospatial Sketchpad.

b. Visuospatial Sketchpad: Visual or Spatial?

The argument to posit a multi-component Visuospatial Sketchpad does not end with an examination of the literature on visual imagery. Evidence also comes from the neuropsychological evidence. Holmes (1918) reports cases of soldiers suffering from gunshot wounds in World War One, who appeared to show evidence of a separable disruption of visual and spatial coding. Hence one patient was able to locate objects accurately ("where"), but not to identify them ("what"), whereas a second showed exactly the opposite pattern suggesting separate coding of *what* and *where*. More recently Farah, Hammond, Levine and Calvanio (1988) reported a patient who appeared to have a deficit in the performance of visual imagery tasks, but had spared function for spatial imagery tasks. The visual imagery tasks involved judgements of colour or size ("which is darker green, the leaves of trees or grass?" or "which is larger, a mouse or an ant?"). Hanley, Young and Pearson (1991) described a patient, ELD, who appeared to have the opposite deficit, namely a sparing of visual imagery, but with a problem in spatial processing.

Psychophysiological measures involving blood flow within the brain also pinpoint the two possible sub-systems that were implicated in visual imagery tasks. Farah (1988) reports that one system appears to be dependent on the occipital lobes of the brain and is involved in representing the physical appearance of objects such as their colour and shape. The other sub-system is responsible for spatial information, and appears to be more dependent on the parietal lobes.

Logie (1989) has in fact conjectured that the retention of visual features and static patterns is due to a passive Visual Store (mirroring the Phonological Store) in the Visuospatial Sketchpad, and irrelevant visual input is thought to enter into it and disrupt

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shall concentrate primarily on the Visuospatial Sketchpad literature. When there is a clear link with its contents (paralleling the irrelevant speech effect). This visual temporary memory system is therefore responsible for merely retaining static images. He also postulates a separate spatial rehearsal mechanism (resembling the articulatory control process) which is involved in the coding and retrieval of sequences of spatial locations and in planning movement. This particular idea remains relatively speculative; it was introduced here mainly to demonstrate how the structure of the Visuospatial Sketchpad has been influenced by that of the Phonological Loop.

c. Are there Visual Similarity Effects in the Visuospatial Sketchpad?

The question is whether confusions arise in memory for visually similar materials. There is indeed evidence that visual confusions occur when subjects attempt to remember visually presented letters or characters that are visually similar to one another. Hue and Ericsson (1988) reported visual similarity effects in immediate recall of unfamiliar Chinese characters. Wolford and Hollingsworth (1974) reported visual confusion errors in the recall of verbal stimuli that were presented visually, but very briefly. Frick (1988) has argued that images in visual Short Term Memory are both unparsed and uncategorised. So, for example, Frick reports that when visual confusion errors occur in retention of letters, there appears to be independent degradation of the parts of the letter. Thus the letter "P" might be mistakenly recalled as an "R'. Also, when subjects are asked to retain visually presented numbers, the font in which the number is printed appears to be associated with the incidence of visual confusion rather than the number itself. So for instance a square block character for the digit '9' is mistakenly recalled as an '8', more often than if the digit '9' is displayed as a continuous curve[13]. Despite these confusions, subjects have no difficulty in identifying the digits when they are presented in different fonts, confirming the idea that the visual confusions arise because of the nature of the code stored in temporary visual memory, rather than because of difficulties in perceiving the presented digits.

There is a lack of data on the visual similarity effect because most visually presented material is phonologically recoded, and so performance will not show sensitivity to visual similarity. However, one way to go about exploring visual similarity is to ensure that subjects are not using their Phonological Loop. There are two approaches to achieving this, one is to get them to perform articulatory suppression whilst performing a visual task, and the other is to use a sample of subjects who use their Visuospatial Sketchpad in preference to their Phonological Loop. The second approach will be expanded upon in the next chapter (in section 2.2.3.1), and it involves using young children as subjects (Hitch, Halliday, Schaafstal and Schraagen, 1988).

Working Memory, I will refer to the imagery literature.

An example of a study that employs the first approach is reported by Della Sala and Logie (1993). These authors recount a study in which letters were selected that are either visually similar or different in upper and lower case (e.g. Kk, Cc, Ss, Pp - similar in upper and lower case, Qq, Bb, Gg, Rr - different in upper and lower case). Subjects were presented with a sequence such as *k C s P*, or *B g r Q*, and would have to write down the sequence in the correct order, and use the correct case for each letter. When subjects had to perform the task and suppress articulation, they had more difficulty recalling the case of presentation of the letters drawn from the visually similar set. As I discussed earlier, articulatory suppression is thought to inhibit the use of subvocalisation, and in the case of letter stimuli, it is thought to inhibit the use of letter names. Thus with articulatory suppression subjects are more likely to rely on some form of visual code for the letters, and make more errors based on visual similarity.

So, to return to the question with which this sub-section began. Yes, the data does suggest that there appears to be evidence for visual similarity effects, and this supports the idea of a temporary memory system that relies on visual codes. However, the effect only appears in particular circumstances, such as under articulatory suppression or with material that is difficult to name. It is probably for this reason that it has not been studied nor replicated as widely as has the phonological similarity effect in immediate serial verbal recall.

Whilst on the topic of visual similarity effects, which seem to emphasise the surface properties of visual stimuli in the Visuospatial Sketchpad, an important developmental study by Hitch, Brandimonte and Walker (1993) should be briefly mentioned. This study highlighted the fact that the Visuospatial Sketchpad retains specifically surface descriptions, whereas Long Term Memory preserves both surface and abstract descriptions. Hitch et al. go on to suggest that it is the verbal coding of visual stimuli, (that I discussed in the Phonological Loop section of this chapter) which appears to encourage the use of abstract visual descriptions.

d. Visual Recency Effects

Recall that one of the most robust phenomena studied within the context of verbal Short Term Memory was recency in immediate free recall. There have been a few studies reporting visual recency effects, the best known of which was reported by Phillips and his colleagues (Phillips and Christie, 1977a,b). The paradigm they developed involved presenting subjects with a sequence of square matrix patterns, with half of the cells of the matrix chosen at random to be filled in. Typically, memory for the patterns was

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[13] An example of the digits in a square block font is: 8 9 and in a curved font: 8 9.

tested in reverse serial order, so that the last pattern presented was tested first using a visual recognition procedure. They reported a marked recency effect, such that the last matrix pattern presented was recognised correctly significantly more often than were items presented earlier in the sequence. Performance was just above chance for all of the other serial positions, including the first. Notably, there was no sign of a primacy effect. Phillips (1983) has suggested that the single item recency effect may reflect the operation of short term visual storage, while what is retained of earlier items involves Long Term Memory.

This conclusion was reported by Broadbent and Broadbent (1981), who examined temporary storage of abstract patterns, irregular patterns and wallpaper patterns. Subjects in their experiment were tested using a probe procedure. Broadbent and Broadbent found a recency effect for the last three items in the series, in contrast to the one-item recency reported by Phillips and Christie (1977a). However, in common with the earlier study, Broadbent and Broadbent found no evidence of a primacy effect in their task. The overall levels of performance were higher than they were for the Phillips and Christie tasks, and this could account for the difference in the number of recency items. The advantage for recency items thus is consistent with the involvement of a specialised visual short term store, and the Broadbents concluded that their visual recency effect appeared to reflect the operation of just such a store.

Avons and Phillips (1987) presented evidence that subjects could use verbal labelling and semantic categorisation in the Phillips and Christie tasks. Broadbent and Broadbent similarly argued that verbal labelling could be used for the pre-recency items. If there is scope for some form of verbal coding, there remains the possibility that subjects may readily retain a verbal code for the last few items in the list, resulting in what is essentially a verbal recency effect.

There was also a question as to whether the visual recency effects might reflect general attentional resources rather than a specialised store. In a second set of studies, Phillips and Christie (1977b) investigated the effect of a secondary task interpolated between presentation of the last item in the matrix series and the probe recognition test. The major finding was that the one-item recency effect is removed by a variety of secondary tasks, and in particular by mental arithmetic. Phillips and Christie argue that since mental arithmetic is unlikely to rely heavily on visualising, this result suggests that visualisation of the last matrix pattern in the series requires the use of general purpose resources rather than a self-contained visual Short Term Memory system (such as the Visuospatial Sketchpad).

Thus the serial position curves for retention of a series of patterns may reflect the operation of general purpose resources, plus the use of a specialised verbal rather than visual resource. This possibility was explored in the study by Logie et al (1990) reported in section 1.3.3.4 in this chapter. They argued that the nature of the interpolated task may well be crucial in determining any disruptive effects, and contrasted the effects of concurrent arithmetic on retention of visual patterns with the effects of concurrent visual imagery tasks. These same secondary tasks were combined with temporary retention of a sequence of letters. Recall that there was a significant disruption of memory for visual patterns by concurrent mental arithmetic. This result is congruent with the impairment by arithmetic of the single item recency effect in the Phillips studies. There was also a disruptive effect of the visual imagery task on letter span performance. However, the most striking feature of the results was a dramatic differential disruption of visual retention by concurrent visual imaging coupled with an equally dramatic disruption of letter span by concurrent arithmetic. These disruptions were much greater than the other two effects.

Logie concluded that there may have been a general processing load involved, but that it was relatively small when compared with the differential disruption associated with the nature of the tasks that were combined. The results are generally highly consistent with the use of a specialised verbal Short Term Store - the Phonological Loop, for the letter span task and a specialised visual Short Term Store - the Visuospatial Sketchpad, for the visual span task. The Visuospatial Sketchpad appears to be involved in visualising and retaining the visually presented pictures, and the Phonological Loop appears to be involved in both the storage of verbal sequences and mental arithmetic.

5. Summary of the Visuospatial Sketchpad

These results in summary suggest that visual short term storage does indeed overlap to some extent with visual perception and visual imagery. There appears to be privileged access to the Visuospatial Sketchpad by visual input. In addition, there appears to be a spatial component that is affected by movement, and there is some evidence for two separate functions dealing with visual and spatial information. There remains some agnosia as to the distinction between the encoding, retention and retrieval of visuospatial information.

1.3.4 Evaluating Working Memory

1.3.4.1 Limitations of the Current Model of Working Memory

1. Specific Problems

Although I have shown that the Working Memory model has been successful in accounting for a large amount of psychological and neuropsychological data., the Working Memory model is far from perfect. There are broadly two types of limitation that one can attach to this model. First, there are criticisms that can be raised at the level of the postulated processes involved in the Phonological Loop, or indeed any other part of the model. For sake of illustration, serious problems with the Articulatory Control Process are now outlined.

The defined role of the Articulatory Control Process in producing the word length effect is complicated by conflicting data. Time-limited spans, from the Working Memory perspective, arise from failures of the subvocal rehearsal processes to refresh active traces within the fixed decay window. But Cowan et al. (1992) have shown that the locus of the word length effect may actually be in the output stage, during the time that subjects are recalling the to-be-remembered items. In one experiment, subjects received random presentations of mixed lists in which word length was varied factorially in each half (i.e. there were four types of list: short-short; short-long; long-short; long-long). Recall order was also varied randomly: a cue appeared at the beginning of the recall period indicating whether the list was to be recalled in a forward or backward direction. Long words produced lower performance, as expected, but only if the task required that long words be output first during recall. Note that at the point of recall, subjects had no way of knowing whether forward or backward recall would be required; thus, the locus of the word length effect seems to be during the response output phase. Other evidence consistent with this conclusion comes from Avons, Wright, and Pammer (1994) who found that the word length effect is smaller in probed recall (which does not require the subject to output the entire list) than it is in spoken serial recall.

According to Cowan (1993), the critical determinant of time limits in span is the speed or efficiency with which subjects can reactivate items during the pauses that occur during the important recall output period. In work with children (Cowan, 1992), he found that silent inter-word pause times during recall increased as the length of the to-be-remembered list grew longer. He concluded that items are lost, presumably due to fixed decay, during the time that other items are being output, but they can be refreshed or reactivated (provided that they have not been completely lost) during the period separating one recalled item from the next. Final memory performance is therefore a function of pronunciation time, during which decay occurs, and of the efficiency with which the remaining items can be reactivated during the response pauses. Most central to the present point however, is that covert rehearsal of the type assumed to be controlled by the Articulatory Control Process is unlikely to be occurring during these inter-response intervals. The pause times are simply too short for rehearsal of the list to be occurring, given what we know about covert rehearsal rates (Landauer, 1962). Instead, some kind of rapid search or scanning process may be operating (Cavanagh, 1972).

There are further results suggesting that memory span and the word length effect are actually rather complex phenomena, influenced by multiple factors. Gathercole and Adams (1993), for example, reported that young children's digit spans are unrelated to their articulation rates. Lapointe and Engle (1990) showed that the elimination of the word length effect under articulatory suppression may depend critically on whether lists are drawn from a large or small vocabulary. Work by Nairne, Neath and Serra (1997) has shown that the word length effect may emerge only when some degree of proactive interference is operative; word length effects are not found for the first few trials in a session.

Other examples of this type of limitation have been echoed in this review by mentioning debates about the irrelevant speech effect (Jones, 1993) or the ambiguity of the structure and rehearsal process of the Visuospatial Sketchpad (Logie, 1989). Similarly, much time could have been spent criticising how central a role the Central Executive plays in the model, and yet how little is understood about its structure and function. This is an important point because I hope to have demonstrated how many of the problems of the Modal Model were solved by the idea of the Central Executive.

2. General Limitations

A second type of limitation is any outstanding failure of the model to explain short term memory phenomena at the functional level. This is not a limitation directed at any one component of the model, but these are shortcomings more than anything else. The model of Working Memory has actually constantly undergone re-specification and modification, and if the current model does not specify how it deals with what seems to be a functional necessity of any model of Short Term Memory, then it is limited in its power. This thesis highlights one particular omission to specify a vital function of the model, and the basic claim is that the current model is not able to explain it. I nonetheless use the Working Memory model throughout as a useful heuristic for considering the nature of (the remaining functions of) Short Term Memory because, as I argue below, it still remains an established and relatively successful framework.

1.3.4.2 Working Memory as a Successful Model of Short Term Memory

In this chapter I have reviewed how the Working Memory Model of Short Term Memory has evolved as a useful framework for understanding Short Term Memory phenomena. The more recent shift away from a passive conception of Short Term Memory has been well characterised in the 'Working Memory' model (Baddeley and Hitch, 1974, 1984, 1993). The 'working' aspect emphasises the active nature of the system.

A cognitively flexible system has been posited, thanks to the combination of the general purpose resources provided by the Central Executive and the more specialised processing and storage functions fulfilled by the Phonological Loop and Visuospatial Sketchpad. Together they seem to be central to many diverse cognitive domains, such as vocabulary acquisition, learning of faces, and consciousness (Gathercole, 1994; Engle, 1996). This is most certainly in contradistinction to the rigid structure and the predominantly verbal nature of the earlier models of Short Term Memory.

Another positive feature of the Working Memory model is its application to cognitive development (Walker, Hitch, Doyle and Porter, 1994). This will be the topic of the next chapter, and I will be illustrate how the model has been invoked to account for certain developmental changes. The changes in Working Memory capacity as a child develops are thought to underpin the more general changes in cognitive abilities, such as reading and arithmetic. A basic assumption, has been that each of the sub-systems has an age-limited capacity associated with it that will account for a developmentally constrained performance on a given task (Hitch and Halliday, 1983).

A further strength of the Working Memory model, is that it has close links with the dual-task methodology, originally from the domain of attention. The basic rationale underpinning this methodology is that if two activities both call upon a common limited capacity component of Working Memory, then subjects will be unable to maintain the same level of performance which they achieved when carrying out only one of the tasks. Articulatory suppression - requiring subjects to continuously articulate irrelevant information such as "the, the, the" during a memory task - appears to block the operation of the Phonological Loop (Baddeley and Hitch, 1974), or to impede the rehearsal process somewhat (Macken and Jones, 1995). Use of the Sketchpad is disrupted when subjects concurrently track a moving visual target (Baddeley and Lieberman, 1980). Activities that appear to place significant burdens on the Central Executive include asking subjects to remember a lengthy sequence of random digits, and generating sequences of random letters (Baddeley, 1986).

The model is especially compelling as it integrates much of the neuropsychological evidence that has been collected, and in so doing it provides predictions for testing patients. In a climate of increasing awareness of Cognitive Neuroscience (e.g. Rugg, 1997), a model that seems to straddle across more than one discipline is most certainly encouraging.

A final feature of the current model's success is its adaptability. Although it hasn't been stressed in this chapter, a gradual process of differentiation and refinement has occurred[14], and due to the model's essentially modular nature, it has the capacity to preserve its general structure while more local aspects are still undergoing change.

[14] The impression that may have been given in the chapter is that all the details of the described model were conceived in the early seventies. This is not the case. The model was updated as new data was presented, and the potted summary here tries to describe the *current* format of the model.

CHAPTER 2

Developing Working Memory

2.1 Chapter Outline

In this chapter, I review the application of the Working Memory model to understanding changes in cognitive development. I concentrate mainly on the Visuospatial Sketchpad, but I will first summarise work on the Central Executive and the Phonological Loop. In the last part of the chapter, I describe the developmental literature on short term memory for object locations as a background for my empirical work, which involves hiding objects in receptacles and immediately probing for the recall of the object locations.

2.2 Working Memory and Cognitive Development

2.2.1 Introduction

In Chapter 1 I argued that the Working Memory model can provide a relatively accurate account of Short Term Memory. This account was derived from, and mainly dealt with the mature adult Short Term Memory system. It should be possible therefore, to ask how this system has matured both in terms of its components and in its characteristics. By investigating how it evolves in development, one can gain better insight and understanding of the adult system.

The starting point is the observation that performance on most cognitive tasks steadily increase with age until it reaches adult levels of competence (e.g. Wilson, Scott and Power, 1987). The assumption is that for each of the three components of Working Memory, there is an age-restricted operating efficiency and use of strategies. These limitations will therefore constrain the information processing tasks that Working Memory is assumed to underpin, leading to age-related performance. The gradual developmental improvement in these tasks reflects the increasing Working Memory capacity and use of strategies with age, until they reach adult levels of competence. Most of the research therefore takes the adult phenomena discussed in the previous chapter, and examines which components develop at a certain age, and what the age-related capacities of these components are.

2.2.2 Central Executive

Developmental analyses of the functions conventionally associated with the Central Executive have provided evidence for an increased capacity in older children to conduct "complex operations" (Siegel, 1994). Complex operations are tasks which impose combined processing and storage demands on subjects. For example, reading and listening span are complex operations because the subject has to process incoming information (sentences) at the same time as retaining the sequence of the final words of the preceding sentences. Another example of a complex operation is backward digit span, where the task is to recall a digit sequence in reverse order. [15]

The question is first of all whether the developmental increases in performance on these complex operations reflect an increase in the absolute capacity of the Central Executive during development. A second question, is given that most of the research on complex operations largely involves language processing and comprehension, how do we know that these tasks are not simply tapping the Phonological Loop?

2.2.2.1 Total Resource Increase or Efficiency Increases?

An explanation of the changes in cognitive functioning that may account for the improvements in Central Executive task performance is provided by a neo-Piagetian characterisation of the limited M capacity introduced by Pascual-Leone (1970) and developed by Case, Kurland and Goldberg (1982). Case et al. specify that the total processing space available to an individual can be flexibly deployed as either processing or storage space. They suggest that the total storage space remains constant over development, but that the operational efficiency of an individual - at executing strategies and processing incoming information - increases over development, which in turn releases storage space.

One task that Case et al. used to explore this theory was counting span, in which children counted the number of objects in a particular display, and then attempted to recall in correct serial order the number of objects in the preceding displays. The combined processing and storage elements of the task mean that it qualifies as a complex operation as defined above. Operational efficiency was also assessed by measuring the amount of time it took the child to repeat back single words. Since This involves both perceptual analysis and motor speech planning activity, it qualifies as a measure of operational efficiency. Using these two techniques, Case et al. provided evidence for a positive linear association between operational efficiency and memory span in children aged between two and six years old: as speed of repetition increased, so did this form of memory span. This correlation was consistent with the view that with increasing age the processing demands diminish releasing storage space. In

[15] The developmental improvement on higher-order Central Executive tasks related to planning and goal-directed behaviour have been reviewed by Pennington and Ozonoff (1996).

addition, Case et al. found that the counting span task was positively correlated with another measure of operational efficiency, namely the speed with which subjects counted the objects in the study. In a further study, Case et al. also found that once differences in operational efficiency were controlled across children and adults by requiring adults to count the objects in the counting span task in an unfamiliar language, span differences disappeared. Again, this fits well with the notion of a constant limit to processing space across all ages. Hence adults have better performance on complex operations compared to children due to increased levels of operational efficiency, unless their operational efficiency is reduced by forcing them to expend extra resources in executing strategies and processing (as was the case in this further study by Case et al.).

In answer to the first question posed above, this particular view argues against an absolute increase in capacity of the Central Executive, but rather for an increase in the efficiency in deploying the limited resources. It should be noted however, that alternative views on the matter exist. One other stand-point mentioned by Gathercole (1998), is of course that the absolute capacity of the Central Executive increases with age. Due to the lack of research on the Central Executive as a whole, and the development of the Central Executive in particular, there is no definitive answer to this question at present.

2.2.2.2 Which Element of Working Memory is Involved in Complex Operations?

The second issue relating to the complex operation tasks discussed above, is whether they actually involve the Central Executive, or whether, because the tasks usually require verbal measures, they depend on the Phonological Loop.

Gathercole (1998) argues that there are five pieces of evidence supporting the idea that complex operation measures and immediate verbal memory span tasks do not tap the same sub-system. The first of these is from a study by Hitch, Halliday, and Littler (1989). The identification time of auditory or visual words were compared with articulation rate as predictors of memory span. The results showed that a linear function described the variation of span with both age and word-length but there was no equivalent relationship between span and identification time. The sensitivity of span to word-length was much reduced when rehearsal was prevented by articulatory suppression. These findings suggest that variation of span with age and word-length is attributable to rehearsal rather than the availability of a central workspace, which is assumed to be involved in the identification time task.[16]

The second piece of evidence cited by Gathercole (1998) which suggests that complex operations do not involve the Phonological Loop, is that of Oakhill, Yuill and Parkin (1986). They demonstrated that there were no differences between children of good and poor reading comprehension abilities (a complex operation) on measures of simple memory span (a Phonological Loop task). The third finding noted by Gathercole is that complex operation measures show consistently higher associations with language comprehension than do simple memory span measures (Daneman and Merikle, 1996).

The fourth result Gathercole reports is that complex and simple span tasks show dissociable ageing effects in adulthood: complex span diminishes from early to late adulthood, whereas simple span is maintained (Siegel, 1994). The final piece of evidence she cites is Morra (1994). In this study, a wide range of both complex and simple working memory tasks were administered to a large sample of children. Morra (1994) discovered that individual variability in the complex tasks, such as counting span and backward digit span, was relatively independent of variability in simple memory tasks across children.

Thus Gathercole (1998) used these collection of findings to argue the case that complex and simple memory span appear to have dissociable origins within Working Memory, with complex tasks tapping the Central Executive, and simple (verbal) span tasks engaging the Phonological Loop.

2.2.3 Phonological Loop

2.2.3.1 Lack of Articulatory Rehearsal Process until 7-Years-Old

Tasks that seem to tap the Phonological Loop, such as digit span show a rapid increase in performance over the early and middle years of childhood (Chi, 1978; Dempster, 1981; Hulme, Thomson, Muir, and Lawrence, 1984). However, as I shall explain, the evidence seems to suggest that the Phonological Loop does not develop in a linear fashion, but rather there is a specific course of developmental change. Investigations have revealed that until the age of seven, the Articulatory Rehearsal Process component

[16] However, to temper the strength of these findings, note that Kail and Park (1994) collected similar measures to Hitch et al. (1989), but calculated from their data set that the natural logarithm of age was correlated positively with measures of memory span but negatively with measures of processing and articulation times. Kail and Park (1994) used causal modelling to demonstrate that age-related change in processing time is associated with a decrease in the time required to articulate numbers and letters, which determines memory span.

of the Phonological Loop is not active, and performance relies exclusively on the Phonological Store (Gathercole and Hitch, 1993). Beyond seven years of age an adult-like cumulative rehearsal strategy emerges and is used to maximise retention in the Phonological Store. Hence nonauditory memory material is recoded into a phonological code that is suitable for the Phonological Loop when possible, and the continuing increase in articulation rate up to the late childhood years further enhances the effectiveness of the Articulatory Rehearsal Process producing additional increments in memory span (Gathercole, 1998).

There are various strands of support for this idea, and many of them stem from the observation that children below the age of seven do not spontaneously use rehearsal strategies in memory experiments, and two of these are outlined in the next sub-section. The core assumption is that rehearsal strategies rely on the subvocal rehearsal process, and so if there is no rehearsal at a particular age, one can assume that the subvocal rehearsal process element of the Phonological Loop is not involved.

The other set of evidence comes directly from the Working Memory literature and demonstrates a specific pattern of development with respect to adult Phonological Loop manipulations such as the word length effect and articulatory suppression. With auditory presentation, children's immediate serial recall is sensitive to phonological similarity and word length[17] at the youngest age groups tested, which is between three and five years of age (Ford and Silber, 1994; Gathercole and Adams, 1994; Hitch and Halliday, 1983). If presentation is in a pictorial modality then children of these age groups (as compared with seven year olds) are not impaired when items have labels that are either lengthy in articulatory duration or are phonologically similar.

The account given to these two sets of results is that with auditory presentation the input can flow directly into the phonological loops of younger subjects, without the need for subvocal rehearsal processes. However, when the input is pictorial, younger subjects remember the stimuli in terms of their visual characteristics (ie. they encode the input using their Visuospatial Sketchpads) rather than recode the pictures into the phonological form required for entry to the Phonological Loop (Hitch et al., 1988; Longoni and Scalisi, 1994). The reason why younger children perform in this way, according to the Working Memory model, is because children lack an Articulatory Rehearsal Process before the age of seven. Further evidence for this comes from Henry (1991), who has shown that articulatory suppression does not have the reliably

[17] Word length effects are actually problematic for this account and this issue is raised a little further on in this section (the relevant sub-section is entitled "word length effects with young children").

disruptive influence on auditory list recall on five-year-old children as it has with older children and adults.

Another line of evidence from the Working Memory literature that the Articulatory Rehearsal Process is not used in early childhood, comes from studies in which measures of both auditory memory span and the rate at which children can articulate the memory items are recorded. Articulation rate and memory span are positively correlated with one another in adults and children over seven but not in children under seven years old. Recall that representations in the Phonological Store will decay after 1.5 to 2 seconds (Baddeley, et al., 1975a) if they are not refreshed by the time-based Articulatory Rehearsal Process. Therefore, subjects with faster rehearsal rates should be able to retain more words and therefore have a higher auditory memory span. This fits with the positive association between the memory span and articulation rate in adults and children over seven. The lack of positive correlation in the younger children implies that they do not use an Articulatory Rehearsal Process since the rate at which they articulate was not connected to their span performance.

1. Evidence for lack of Rehearsal below 7 Years

One finding that demonstrates a lack of rehearsal strategies in younger children comes from Flavell, Beach and Chinsky (1966). They failed to find any evidence for overt signs of rehearsal in children under seven years old, as indexed by a lack of lip movements or whispering in the interval between memory presentations in immediate memory tasks. Another approach was taken by Johnston, Johnson, and Gray (1987) who studied the immediate serial recall of five year old children. When tested with sequences of nameable pictures, there was no sensitivity to whether the picture names were long or short in articulatory duration.

However, when Johnston et al. followed this with training the children in the use of overt and covert cumulative rehearsal strategies, the children showed superior recall of pictures with short names over long names - the word length effect had been induced after training. This study provides evidence that subvocal rehearsal is not used spontaneously at this age. Furthermore, it shows how this strategy can be induced with training, indicating perhaps that the Articulatory Rehearsal Process is in fact present at this age, but is not usually operative.

a. Word Length Effects with Young Children?

The assertion that the Articulatory Rehearsal Process does not emerge until the middle childhood years has been advanced above, but there are still a few problems with this view. The first relates back to the finding discussed earlier in this section that even with young children who are not supposed to have a developed rehearsal process, one can still obtain a word length effect with auditory presentation in serial recall (Ford and Silber, 1994; Gathercole and Adams, 1994; Hitch and Halliday, 1983). This should not be the case if children cannot rehearse, as the word length effect has been attributed to the Articulatory Rehearsal Process. The most likely explanation is that word length effects in Short Term Memory do not come exclusively from rehearsal (Gathercole, 1998)[18].

As noted in the last chapter (section 1.3.4.1), there is sufficient evidence that the greater delay in output involved in the spoken recall of lengthy versus short memory items may itself be enough to account for extra decay in the Phonological Store and hence impair recall accuracy (Avons et al., 1994; Brown and Hulme, 1995; Cowan, Keller, Hulme, Roodenrys, McDougall and Rack, 1994). In keeping with this view, children below seven years of age do not show word length effects even for auditory material if memory performance is not sampled by a serial spoken recall procedure, and hence is not subject to differential output delays for short and long items (Henry, 1991).

b. Memory Span Increases before Rehearsal?

Another problem for this particular account of Phonological Loop development is that memory span which taps the Articulatory Rehearsal Process, has already increased prior to when rehearsal emerges at seven years of age (e.g. Gathercole and Adams, 1994). One possibility is that the span increase before the age of seven is because as children get older they are able to articulate items more rapidly at recall, and they are therefore able to reduce the decay of memory items in the Phonological Store prior to output. As Gathercole (1998) points out, the lack of fine-grained analysis of developmental change in immediate memory span in this pre-rehearsal period means that this hypothesis has not as yet been tested.

2. The Role of Long Term Knowledge in Phonological Loop Tasks

Thus far, the account of Phonological Loop development has explained increases in memory span in terms of increased rates of articulation. If this is true, then one would predict that if articulation rates are held constant, then the differences between performance on memory span tasks should be eliminated when comparing two different age groups. This has been tested in two studies (Henry and Millar, 1991; Roodenrys, Hulme and Brown, 1993) which have shown that articulation rates provide a

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[18] Note that more extreme positions have been taken on this issue. For instance, Brown and Hulme (1995), have concluded that ".....many of the data that have hitherto been taken as evidence for subvocal rehearsal can be explained in terms of simple models without rehearsal." It is not within the scope of this discussion, however, to consider other models.

significant, yet only partial account of the change in memory span during childhood. In other words, Phonological Loop development does not provide a full explanation of what changes in childhood. The increase in long term knowledge seems to be the additional factor involved in the steady increases in memory span (Gathercole, 1998), as I now describe below.

The contribution of the mental lexicon (the long term store of lexical knowledge) to immediate serial recall was demonstrated by Hulme, Maughan and Brown, (1991). In their study they found an increase in short term memory performance when lists contain words as opposed to non-words. Since the word and non-word memory stimuli did not differ in articulation rate and amount of phonological information, this suggests that the *lexicality effect* (ie. the recall advantage of words over non-words) must arise from the additional long term knowledge one possesses about the familiar words. Other studies by Hulme suggest that the lexicality effect is mediated by phonological knowledge rather than nonphonological attributes such as word meaning (Brown and Hulme, 1992; Hulme et al., 1991). Hulme asserts that stored phonological knowledge about the structures of words is used to "fill in" incomplete information in the representations of words in the Phonological Store, in a process called *redintegration.* The poorer memory for non-words is because subjects cannot benefit from the advantage of redintegration to recover missing information in the Phonological Store.

Findings by Roodenrys et al. (1993) may lend support to the idea that it is the undeniable increase in size of the mental lexicon that contributes to memory span tasks as age increases. In comparing 6- and 10-year-olds on memory span, these researchers noted a greater lexicality effect in the older group that was not accounted for in terms of differences between the two groups in articulatory speed. The results just missed statistical significance but they provide encouraging support for the idea that the developmental increase in memory span is gained in part by an increasing mental lexicon.

It is not only the fact that children become more familiar with words as they grow up that may increase performance on the span task, but an even more basic aspect of long term phonological knowledge could also play a part. This is the increase in the knowledge about the probabilistic structure of the sound combinations in the native language of the child. Gathercole and colleagues have shown in several studies (Gathercole, 1995; Gathercole and Martin, 1996; Gathercole, Willis, Emslie and Baddeley, 1991) that children are better at repeating multisyllabic nonword stimuli when the wordlikeness of the nonwords, as judged by adults, is high (e.g. *commerine*) versus low (*loddernaypj*). Similarly, English-speaking children recall non-word sequences more accurately if the nonwords contain adjacent phoneme pairs that are high in probability of occurrence within English (Gathercole, Frankish, Pickering and Peaker, submitted). So even for unfamiliar items, one's existing knowledge about the structure of the language can be utilised to improve recall accuracy. Finally, Gathercole (1995) has provided further evidence for this by demonstrating that 5-year-olds show a greater advantage in repetition accuracy for nonwords of high as compared to low wordlikeness than did 4-year-old children.

3. Specific Language Impairment as a Deficit to Phonological Store

As mentioned in the previous chapter (section 1.3.3.3), a primary function of the Phonological Loop is to support language learning (Gathercole and Baddeley, 1993). Hence children with specific language impairment (SLI) have been found to display extremely poor phonological short term memory function. Briefly, the condition is associated with persisting deficits in the production and comprehension of language, including particularly poor vocabulary development, immature syntax and impaired grammatical morphology (Bishop, North and Donlan, 1996). Although there are a variety of accounts for the deficit underlying SLI (see Bishop, 1992, for a review), Gathercole and Baddeley (1990, 1993) have asserted that the deficit arises from extreme limitations in the capacity of the Phonological Store component of the Phonological Loop. It is thus the poor temporary storage of incoming speech stimuli that is the basis for the difficulties encountered by SLI children in setting up durable long term phonological representations of novel words. It should be noted that this hypothesis is a little controversial, as there is data which seems to imply that the impairment is actually at the level of perceptual processing, and not of memory (Montgomery, 1995).

2.2.4 Visuospatial Sketchpad

Although the changes in the Visuospatial Sketchpad have not been documented to the same extent as the Phonological Loop, the basic understanding is that younger children depend more than older children and adults on using their Visuospatial Sketchpad for encoding visual material. This is now expanded upon below.

2.2.4.1 Younger Children's Reliance on the Visuospatial Sketchpad

As I mentioned earlier in section 2.2.3.1, Hitch et al. (1988) presented a series of pictures of nameable objects for recall and found that 5-year-old children are impaired in recalling memory lists in which the objects share many physical features (e.g. *pen, fork, comb*), as compared with objects who share few features (e.g. *doll, bath, glove)*. Subjects who are ten years old however, showed no sensitivity in recall to the visual similarity of the pictures, but were impaired when the pictures had lengthy names (e.g. *umbrella, kangaroo, policeman)*. As I explained, these and other findings reported by

Hitch and colleagues (Hitch, Woodin and Baker, 1989) imply that older children adopt a strategy of verbally recoding pictures where possible and so use the Phonological Loop to mediate performance on a "visual" memory task. As young children are not able to generate phonological codes for the visual items (due to their immature Articulatory Rehearsal Process), they are forced to rely instead on their recall of the purely visuospatial characteristics of the memory stimuli. For this reason, younger children are particularly good candidates for studying the Visuospatial Sketchpad, as one can be confident that their performance on visual tasks exclusively reflects this part of Working Memory.

1. Pattern Span Task

Given that there is this tendency to recode visually presented items from about seven years of age, then if one is to chart the development of the Visuospatial Sketchpad, it is important to find a visual memory task where this will not happen. One way of going about this is to find a memory task in which the stimuli cannot be recoded into a phonological form. Wilson et al. (1987) devised just such a paradigm: the pattern span task. In this task, a two-dimensional pattern composed of squares that are either filled or unfilled is briefly displayed on each trial. The child is then shown the same pattern with a single filled block missing, and is required to point to its original location. The number of blocks in the test patterns are then increased until memory accuracy falls below a specific level (e.g. two consecutive corrects), yielding for each individual a span measure of number of blocks reliably remembered.

Using their technique, Wilson et al. (1987) demonstrated that visual memory span increases substantially and regularly between 5 and 11 years, by which time adult levels of performance are achieved. Five-year-olds can manage about four blocks, whereas by eleven years of age children can match adult performance (around fourteen blocks). Similar patterns of development of visual pattern spans were also obtained by Miles, Morgan, Milne and Morris, (1996). In their study, they adapted the standard pattern span procedure slightly by introducing a different method of testing. Instead of the partial recall procedure in the original paradigm, the method of memory test was recognition (participants had to judge which of a pair of patterns had been judged previously) and free recall (a blank matrix was presented and subjects had to point to the squares that were filled in the test stimulus). In each case, relatively steep developmental increases were obtained across groups of children aged 5, 7, and 10 years, and adults, with span estimates lower across all ages in the more time-consuming free recall condition. The developmental function for the free recall version of the pattern has since been replicated (Pickering, Gathercole and Hall, submitted).

a. Other Working Memory Components in the Pattern Span Task

It may be appealing to interpret these data from the pattern span task as evidence of age-related changes in the capacity of the Sketchpad to retain visual information. Despite the apparently nonverbal nature of the pattern span test stimuli, both the Wilson et al. (1987) and Miles et al. (1996) studies actually provide additional evidence that a substantial part of the developmental increase in pattern span arises from the contribution of memory components other than the Visuospatial Sketchpad.

Wilson et al. (1987) tested pattern span under a variety of concurrent task conditions, and found that interpolating a 10-second interval of spoken arithmetic-related activity (counting backwards aloud for older groups, forward counting for the youngest age group), between presentation of the pattern and recalling it reduced pattern span considerably, and that the magnitude of this disruption increased progressively between five and eleven years. Engaging in irrelevant mental arithmetic is widely believed to require the involvement of the Central Executive (Baddeley and Hitch, 1974), and irrelevant articulation appears to block the Articulatory Rehearsal Process (Baddeley et al., 1975a). Therefore, the disruptive effect of spoken mental arithmetic on pattern span for older children and adults indicated significant involvement of either or both of these two nonvisual components of Working Memory in the pattern span task. At least some of the growth in children's ability to remember visual patterns therefore appears to mirror increasing use of nonvisual strategies to mediate memory performance rather than enhanced visual memory per se.

The nature of the interpolated task used by Wilson et al. (1987) does not allow one to identify whether the older children were using the Phonological Loop to supplement the Visuospatial Sketchpad in the pattern span (by verbally recoding stimuli) or the Central Executive. Other findings imply that both of these components may be active in the task. Firstly, recall from section 1.3.3..4 in Chapter 1, that earlier work with adults (Phillips and Christie, 1977b) had already established that recall of similar matrix-style visual patterns is greatly disrupted by subsequent silent mental arithmetic, implicating Central Executive involvement in memory for patterns. Secondly, there were other conditions in the Miles et al. (1996) study, where concurrent articulatory suppression disrupted the visual pattern span (particularly in the recognition and partial recall versions) in 10-year-olds and adults, suggesting the additional involvement of the Phonological Loop. In addition, the fact that both the Central Executive and the Phonological Loop are involved in the visual pattern task is borne out by the fact that the concurrent task in the Wilson et al. (1987) study loaded on both the Central Executive and the Phonological Loop, resulting in a considerably greater disruption on the visual task than was found in the Miles et al. study in which there was only a concurrent Phonological Loop task.

2.2.4.2 Does the Visual Store or Spatial/Movement Rehearsal Process Account for Developmental Changes?

One issue that has yet to be resolved is to do with the nature of the development of the Visuospatial Sketchpad. It will be recalled (from section 1.3.3.4) that Logie (1994) has suggested that there are two components which may constitute the Visuospatial Sketchpad; a Visual Store (mirroring the Phonological Store) and a Spatial/Movement-based Process (mirroring the Articulatory Rehearsal Process). Given that the evidence reviewed above suggests that the Phonological Store emerges first in development, could it be the case that the Visual Store develops first, followed by the other component?

A possible direction for investigating this issue in a concrete fashion, stems from the fact that concurrent task techniques are available that have been shown to disrupt the separate components. The Visual Store is disrupted by irrelevant visual information (Quinn and McConnell, 1996) and tapping impairs spatial memory (Smyth and Pendleton, 1989). By applying these techniques, it should theoretically become possible to analyse the contributions of the different components of the Visuospatial Sketchpad to the developmental changes in visual memory.

2.2.4.3 Corsi Block Task

Another paradigm that has been useful in helping to chart the changes during development in the performance of visuospatial tasks has been the Corsi blocks task. As mentioned in the previous chapter in the context of the adult Visuospatial Sketchpad (see section 1.3.3.4), a three dimensional display of nine blocks is placed in front of the participant, who observes the experimenter tapping the blocks in an unsystematic sequence. The task is then to repeat exactly the same sequence by tapping the correct blocks in the correct order. As in the digit span task, the number of memory items is increased systematically up to the point at which the participant can no longer reliably reproduce the correct sequence, and a span estimate is obtained. This technique has the advantage of being a "purer" measure of the performance of the Visuospatial Sketchpad (see section 2.2.4.1), relative to the pattern span task. Similarly, because it bears so much resemblance to the standard digit span task, it allows one to understand the relationship between the development of the Visuospatial Sketchpad and the development of the Phonological Loop.

1. Digit versus Spatial Span

The developmental course of children's memory spans on both the digit span and the Corsi blocks tasks was investigated by Isaacs and Vargha-Khadem (1989). In their study, children aged between seven and fifteen years were tested for their performance on these two measures. Both span tasks showed a regular increase across this age range corresponding to about 1.5 items of span, with Corsi span at each age range lagging about one item of span behind digit span.

One interesting feature of the Isaacs and Vargha-Khadem (1989) study was that for both tasks, children were tested on their forward and backward recall of the test sequences. The results showed that backwards digit span performance was greatly reduced relative to the forward span. This is in line with normative data on forward and backward digit span provided by standardised ability tests such as WISC-R (Wechsler, 1982). However, the study revealed that the Corsi span task was equivalent whether recall was tested in a forwards or reverse order. This indicates that order information is extracted in a fundamentally different manner from spatial memory than how it is extracted from the Phonological Loop. It should be noted at this point, that subsequent findings from adult data suggest that the contrasting impairment with backward recall may be due in part to the differential availability of item information in the conventional Corsi blocks and digit span procedures (Farrand and Jones, 1996). The "items" are present in front of the subject in the Corsi task, but they need to be retrieved in the standard digit span task.

2.2.4.4 Separating Spatial, Visual and Phonological Working Memory Development

Pickering et al. (submitted) investigated children's abilities to retain spatial, visual and phonological information in Working Memory. In an initial study, 5- and 8-year-olds were tested on the standard pattern task, Corsi block recall and digit span. Scores on each task were uncorrelated with one another, which gives reason to suggests that spatial, visual and phonological Working Memory capacities are dissociable in children of a relatively young age.

In a subsequent study, Pickering et al. constructed versions of the pattern span and Corsi block task that were directly comparable except in terms of temporal order. To achieve this, a few modifications to the standard tasks were made. Their pattern span stimuli were arrays of squares containing equal numbers of filled and unfilled blocks, similar to those employed by Wilson et al. (1987), but the subject was presented each pattern for 2 seconds on a computer screen and then had to indicate on an empty square the locations of the filled blocks they had just viewed. Note that this technique corresponds to the free recall technique used by Miles et al. (1996) which I described earlier in section 2.2.4.1. Span was thus measured in the usual way by increasing the number of squares until the children were unable to perform accurately.

For the spatial task, the subjects viewed a computer screen which initially just displayed an empty square which filled with blocks one at a time. The child's task at the end of the sequence was to point to the squares that had been filled at presentation, in the same order as they had occurred on the screen. Hence this is a two dimensional version of the conventional Corsi block task. Across the pattern span and spatial tasks, the item content (i.e. the location of the filled blocks in the squares) was made equivalent, as was the method of recall. The tasks only differed with respect to the presence of order information coupled with the requirement to recall it in the spatial task. Children aged five, seven and ten were participants in this part of the study.

There were two important findings in this part of the study. First, scores on the pattern span and spatial span were uncorrelated with each other, despite the close similarity between the information content and paradigms employed in the two cases. This pattern of data seems to be consistent with the notion that different memory capacities or sub-systems may underpin memory for visual material with and without a temporal dimension. Similarly, the idea of a distinction between a Visual Store and a spatial movement based system in the Visuospatial Sketchpad, in line with Logie (1994), receives encouraging support.

The second important finding that emerged from this part of the study, was that the age-related increase in span for both tasks revealed a much steeper function for the pattern span relative to the spatial span task. Specifically, whereas the two span estimates were similar in the younger age groups, the benefits to pattern span over spatial span were very substantial indeed by ten years of age. Hence these differences in the developmental functions of the two tasks can be taken as further evidence for two separate systems. In addition, the steeper increase in pattern span with age may reflect the increasing use by older children of nonvisual strategies to supplement memory for the visual patterns (as described above in section 2.2.4.1 in relation to the Wilson et al., 1987 study and the Miles et al., 1996 study), but not for the temporal order of the elements in the spatial task. This would imply that memory for spatial information that is distributed across time is extremely restricted, and, unlike other slave components, does not enjoy the opportunity for other sources of memory support that are available for purely visual configurations. Of course the alternative hypothesis to this is simply that the two sub-systems have different age-related capacities, as revealed by the functions. Once again, the dual-task techniques for disrupting visual or spatial components of Working Memory mentioned at the end of section 2.2.4.2 are needed to clarify these issues.

2.2.4.5 Williams Syndrome

Gathercole (1998) has argued that an important role of the Visuospatial Sketchpad is in mediating the long term learning of the visual and spatial co-ordinates of novel objects, in much the same way as the Phonological Loop appears to be crucial in supporting the learning of the sounds of new words. This idea receives support from a patient (ELD) mentioned in section 1.3.3.4 in the previous chapter (Hanley et al., 1991), who, it will be recalled, had very poor performance on the Corsi task and other tests of immediate visuospatial memory. More interestingly, ELD was unable to learn new routes such as the way back to her new flat and was unable to learn to recognise new faces.

Based on this, one would have predicted that children with severely compromised abilities to retain visuospatial information temporarily should also be impaired on learning new spatial routes and faces. One group of children who provide the opportunity for testing this hypothesis are children with Williams syndrome. Williams syndrome is a rare genetic disorder leading to learning disabilities that are considerably more substantial in the aspects of visuospatial cognition than language, including Working Memory (e.g. Bellugi, Marks, Bihrle and Sabo, 1988). Williams syndrome children support the hypothesis that impaired short term visual retention adversely effects the long term learning of visual information on the one hand, in that they are certainly impaired in learning new spatial patterns (Vicari, Brizzolara, Carlesimo, Pezzini and Volterra, 1996). On the other hand, the fact that they do not seem to have a problem in learning new faces (Karmiloff-Smith, Klima, Bellugi, Grant and Baron-Cohen, 1995) seems to suggest that their visuospatial impairments reflect a more general long term learning deficit.

2.3 Development of Memory for Object Locations

The Visuospatial Sketchpad seems a natural candidate for the temporary storage of object locations. Inspecting the developmental research on memory for locations in a small-scale two-dimensional space reveals that there are a variety of methodological techniques which are based on one of three theoretical approaches. Firstly there is the issue of automatic versus effortful processing of spatial information (Hasher and Zacks, 1979). Next there is the question of the effect of scene schemata on spatial memory (Mandler, 1983), and thirdly, there are the sort of investigations outlined above that are trying to specify the nature of the Visuospatial Sketchpad. The relevant results are summarised below for the first two classifications, followed by a summary of the variety of methodological approaches. Note that there is a lot of work on children's searching behaviour (e.g. Herman, 1980; Herman, Kolker and Shaw, 1982), but this is usually in real three-dimensional environments. For the sake of comparison to the paradigm that I use in my empirical work, the summary does not include these studies. Moreover, these studies on searching behaviour also involve subjects using a fair amount of problem solving strategies in addition to any retention of object locations in Working Memory.

2.3.1 Automatic versus Effortful Distinction

Most of the studies about memory for location are guided by the theory of Hasher and Zacks (1979). In their distinction of automatic versus effortful processing, the authors postulate that time, frequency, and location are automatically encoded attributes of items. Hasher and Zacks formulate several criteria for automaticity, among them the lack of age-dependent variation in task performance. Hence, in order to evaluate the Hasher and Zacks theory, researchers have examined memory for the locations of objects in children (and adults) of different ages. Some evidence has shown that young children can be very capable of remembering the association between an item and its spatial location, such that improvement in performance has not improved with age (Ellis, Katz and Williams, 1987). However, it is also apparent that such improvement can occur and can be quite pronounced (Mandler, Seegmiller and Day, 1977; Park and James, 1983; Pezdek, Roman and Sobolik, 1986).

2.3.1.1 Item, Location, and Item-Location Memory

Among other things, what emerged from the work of Hasher and Zacks (1979) was the need to distinguish between three facets of memory when generally dealing with a task involving the recall of the locations of objects (Schumann-Hengsteler, 1992). The first is a capacity to remember the items themselves *(item memory);* this would be measured by having the subject select the items that had been hidden from a larger set at test, for example. The second type of memory is that of the spatial distribution of the items, as revealed by a subject's ability to specify which of a set of locations have been used *(location memory).* Thirdly, memory for the actual item-location associations *(item-location memory),* as revealed by the subject's performance on knowing the whereabouts of a given item as being in a given location. Hence, Walker et al. (1994), for example, utilised these distinctions in a study which provided evidence against the proposal of Hasher and Zacks.

2.3.2 Effect of Scene Schemata on Spatial Memory

Mandler (1983) emphasised the importance of general world knowledge in remembering the locations of objects, and this has generated studies on children's memory for object locations. Mandler (1983) postulates that knowledge is organised in scene schemata. They are activated whenever spatial information is presented in the usual, i.e. everyday, way. In this context, two developmental studies (Mandler and Robinson, 1978; Mandler and Stein, 1974) demonstrate that organised scenes are easier to recognise than disorganised scenes. However, the linear increase of recognition performance from 7-year-olds to adults holds only for organised scenes. For disorganised spatial information, the performance of children between seven and ten years does not vary, and is rather low. Mandler and Robinson (1978) interpret this finding in terms of available world knowledge that facilitates the performance in visuospatial recognition, even for the youngest age group. This seems to mirror the effects of lexical knowledge on the Phonological Loop tasks reviewed (in section 2.2.3.1) in this chapter.

2.3.3 Methodological Approaches

As mentioned above, perhaps in part due to the three different foci of these studies, there are a wide variety of methodological approaches to investigating memory for object locations in the literature. Some studies have a very short presentation time of the material (Hitch and Walker, 1991), whereas others present it for more than one minute (Naveh-Benjamin, 1987, 1988). Sometimes stimuli are presented serially (Ellis et al., 1987; Park and James, 1983), and sometimes simultaneously (Mandler et al., 1977). Some studies use drawings (Park and James, 1983; Schumann-Hengsteler, 1992), others present colour photos (Ellis, 1990) and some use computers for presenting coloured shapes (Walker et al., 1994). In some cases, photos are even accompanied by the verbal labelling of the pictorial material (Ellis, 1990). Another aspect which varies from study to study is the type of response required from the subject (e.g. recognition or recall). Additionally, several studies use the same location occupied by different items on successive presentations. Finally, the total number of critical loci to be remembered in the cited studies varies from two (Park and James, 1983) to twenty (Naveh-Benjamin, 1987, 1988).

2.4 Summary and Conclusions

2.4.1 Working Memory as Applied to Development

As Baddeley (1986) himself has noted, the Working Memory model was not intended to explain data from developmental psychology, rather it is a model of adult Short Term Memory. However, it has generated numerous studies in developmental psychology; most of these studies have attempted to determine whether there are similar effects in children. Many of these studies have focused on the phonological domain in trying to map the development of the components of the Phonological Loop that have been identified in studies with adults. Although some of this particular work converges with

Flavell's work on rehearsal from over two decades ago, it is clear that issues relating to the development of the components of the Phonological Loop remain controversial. Developmental change in Visuospatial Sketchpad tasks has been somewhat less widely studied even with respect to the development of spatial span[19]. Although it does seem clear that children under the age of five depend more than older children and adults on using their Visuospatial Sketchpad for encoding visual material.

As with adult research, the explicit exploration of the Central Executive is even less extensive, because of its somewhat more elusive nature as a "conceptual black box" (de Ribaupierre and Bailleux, 1994). What does emerge from developmental analyses of the functions usually associated with the Central Executive, is that there is some limited evidence for an increased capacity to conduct complex operations. No separation of the components of the Central Executive (that were found in work with adults) have been documented in developmental work.

What becomes clear, for the sake of this thesis, is that the Working Memory model can be applied to development certainly at the gross level of a tripartite system. The nature of the maturation of each component, and how these components interact during the developmental course is less clear. Nevertheless, the model can be postulated as a useful heuristic in understanding development, in that children of a given age will have a sub-system that may or may not be involved in a particular task. The subsystem will have an age-limited capacity, and this will constrain performance on a short term memory task. In addition, this basic structure implies that interference will occur between tasks that draw on resources from the same sub-system, in a broadly similar way to how this occurs in adults.[20] As a result of this, one can use dual-task methodology to make predictions and to interpret results.

2.4.2 Development of Memory for Object Locations

There are three points relevant to my review of the development of memory for object locations that I would like to mention here, all of which link up with my conclusions and summary of developmental Working Memory. The first relates to the issue of the capacity of the Visuospatial Sketchpad: the component of the system that is involved in the coding of object locations for short periods. Because there are so many ways of measuring the performance of the Visuospatial Sketchpad, unlike the Phonological

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[19] I suggest a reason for this in the next section (2.4.2).

[20] Note that Hale, Bronik and Fry (1997) have provided evidence that 8-year-olds show a degree of interference from concurrent tasks which separately tap the Phonological Loop and the Visuospatial Sketchpad. They conclude from this that some executive levels of efficiency in dual-tasks do not reach

Loop where digit span has been the main measure, it is difficult to say in a definitive sense what the capacity of the Sketchpad is at a given age. Rather, for a given visuospatial task, there will be an associated age-related capacity.

Secondly, since there is a case for young children not being able to generate phonological codes for visual items, forcing them to rely on purely visuospatial characteristics of the memory stimuli, younger children are particularly good candidates for studying the Visuospatial Sketchpad. Therefore in an object location task with pre-school children, one can be confident that their performance on this visual task exclusively reflects storage in this part of Working Memory.

Thirdly, much of the work on memory for object locations focuses on children from the age of five and upwards, missing out the 3- and 4-year-old age range of the subjects tested in my empirical work. The implication of all this, is that in establishing the capacity of a 3- or 4-year-old on an object location task, there is a necessity to gain an independent measure of the age-related capacity on a specific task through pilot-testing. Once this has been done, however, there is a degree of confidence that this will be an accurate measure of Visuospatial Sketchpad capacity. As I will mention in the next chapter (section 3.5), this rationale plays an important role in the paradigm that I have used in order to demonstrate the independence of the Current State Buffer from Working Memory.

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adult levels until about ten years of age. This reflects a development in the function of the Central Executive.

CHAPTER 3

The Current State Buffer and Working Memory

3.1 Introduction

During the course of the last two chapters, I have presented the Working Memory model (Baddeley and Hitch, 1974, 1993) as a viable framework for considering Short Term Memory experiments. I have also considered how it can be used as a useful heuristic for understanding cognitive development. However, the central argument of this chapter develops a point that was briefly introduced at the end of the first chapter (in section 1.3.4.1). This is that a general limitation of the Working Memory model is that it seems to omit a particularly important component of any theory of Short Term Memory. This component is discussed, and the above argument is crystallised in a discussion of how to demonstrate the existence of such a component experimentally, in a developmental context.

3.1.1 Chapter Outline

The chapter formally introduces the main subject matter of this thesis - the Current State Buffer. I first discuss the concept of a Current State Buffer, motivated by a few examples of the possible uses of the Current State Buffer in every-day life. Then, moving away from just mere intuition about such a construct, I describe a study which has successfully utilised this notion - Barreau and Morton's (submitted) "bag task". I then present the thinking behind a novel experimental method which was designed in order to demonstrate the existence of such a Buffer as distinct from Working Memory - the "Tidy Emu Paradigm". The chapter then continues with a brief commentary on the choice of task and subject population involved in the empirical work of the thesis. The chapter then draws to a close with some details and predictions of the initial study that I designed to demonstrate the independence of the Current State Buffer from Working Memory.

3.2 The Current State Buffer

The 'Current State Buffer' is responsible for tracking the location and status of relevant or important stimuli in an individual's immediate environment (Abeles and Morton, in press; Barreau, 1997, Morton, 1997). Of necessity, we must have access to the *current* representation of our personal environment, and *not* former states of it, in order for us to effectively operate in the present. The Current State Buffer is conceived of containing the representations of the whereabouts or status of stimuli, such as objects, individuals and mental states. Therefore keeping track of one's current environment means that these representations are constantly undergoing destructive updating as their whereabouts or status change with time. The representations in the Current State Buffer enable an individual to act upon their environment in a rapid and effortless way, and may help the individual to anticipate future states of the environment. The Buffer stores these representations automatically at the immediate level of attention, and they may be seen, to a certain extent, as comprising a part of an individual's consciousness. And to recapitulate on a crucial point mentioned above, the Working Memory model (Baddeley and Hitch, 1974) seems to neglect to specify how the model deals with these types representations. Interestingly, Baddeley and Hitch (1993) *have* made mention of a roughly similar psychological capacity, although it is not actually a part of Working Memory but a function of the ubiquitous recency mechanism. Their account is not fully specified, and will be returned to in section 5.3.1 in Chapter 5.

A feature of the Current State Buffer is that it updates the representations of the environment that it is constantly registering. Bjork (1978) has also devoted a paper to how human memory is updated. He distinguished two mechanisms of updating, firstly *destructive updating,* whereby earlier versions of a representation are completely destroyed. The second mechanism is termed *structural updating,* whereby earlier versions are preserved but order and recency information is built into the series by some structural principle. Clearly, the first mechanism is similar to the type of updating proposed to occur in the Current State Buffer, in that former representations of the environment in the Current State Buffer are wiped out in favour of the current state of the environment. However, Bjork's notions of updating refer to principles governing both Long and Short Term Memory. Moreover, when discussing what determines which of the two types of updating occur, Bjork states that

> *"The more there is some principle that connects or orders successive inputs, the fewer are the chances that order information will be lost* (structural updating). *If there is little or no superordinate structure, however, order information is lost rapidly"* (destructive updating). (Bjork, 1978, p. 238; non-italicised words are my annotations)

In distinction to this, the inputs that are registered in the Current State Buffer, and are therefore destructively updated, have nothing to do with lacking a "superordinate structure". These inputs are coded in the Current State Buffer due to their importance to the individual, and their representations will be destructively updated as their status changes with time.

In further contradistinction to the ideas of Baddeley and Hitch (1993) and of Bjork (1978), the Current State Buffer is seen as a separate component of memory that is actively concerned with tracking and updating representations. Furthermore, the Current State Buffer only deals with the representations of stimuli that are important to the individual's local physical or psychological environment. If the representation of a stimulus does not qualify for entry into the Current State Buffer, then that stimulus will not have priority for being tracked by the system in this way, although its representation may be updated or kept "recent" through some other means. Indeed, it is these latter representations that may be governed by the ideas of Bjork or by the recency mechanism.

To portray the functional nature of such a Buffer, and indeed the need for such a Buffer, consider the complex environment of a social gathering, such as a party. In a strange room, the locations of key objects such as the drinks, the dance-floor, or specific friends (or enemies) in the room, are all immediately at hand. If one was then given directions to the bathroom, then just maintaining such a representation temporarily is not likely to interfere with one's knowledge of these aforementioned important stimuli in the immediate environment[21]. If it did, our social interactions would be adversely affected. Similarly, our orientation within an environment (for example negotiating the self same environment to return our glass to the bar before exiting the room), would fail.

The scenario where parents are out on a day-trip with their 2-year-old son, who has a habit of wandering-off on his own, is another instance of where the function of the Current State Buffer becomes apparent. If one of the places they visit was a museum, the parents would constantly have to "keep an eye" on their son as they inspected exhibits, or stood by a map to figure out the directions to the café. Their immediate memory for the information from an exhibit's caption, or for the way to the café would not be expected to interfere with the representation of their son's whereabouts. Hence a parent would not have any trouble in simultaneously maintaining either of the two pieces of information together with a representation that their son was on the car-ride, or with the other parent on the other floor, or playing with another toddler by the window. In this way, the Current State Buffer would keep track of where the child had just wandered, constantly updating his whereabouts. The chances of losing the child would increase if the parents did not remember anything but the *current* representation of the child's location.

Another example which may serve to demonstrate the need for a Current State Buffer to maintain our orientation in time and space is that of people seated around a table during a game of cards. All the players will have a representation of where each of the other

[21] Clearly this example assumes that learning the route to the bathroom is a novel Short Term Memory task, although this representation may subsequently be stored in the Current State Buffer.

players are seated. Without looking at their cards, they will have a representation of the current hand they are holding. They will also presumably have a representation of what they think the other players' cards are, and possibly a representation of what they think the other players *think* that their own cards are. If they have drinks at the game, then the players will have a representation of whether or not they have any drink left in their glass, and where the glass is. Of course these are representations of stimuli (in the broad sense of the word) in their immediate physical environment, but other representations in their Current State Buffers may include stimuli that are further afield, such as what city or town they are in, the location of their coats and where they parked their cars. It is apparent from this description that these sorts of representations need to be constantly destructively updated in an automatic fashion in order for the system to run smoothly; proactive interference does not seem to happen.

A final illustration that may prove useful in portraying the use of the Current State Buffer as something independent of Working Memory[22], comes from thinking about a hypothetical Short Term Memory experiment. Consider what would happen in an experiment where a subject has to remember where various tokens were hidden in various different coloured containers. This task would probably involve storage in the Visuospatial Sketchpad. If the subject is given the money that they will receive for doing the experiment, and if this money happens to be put in one of the containers, an interesting situation arises. It is conceivable that the subject's Current State Buffer will track the location of the money in one of the containers, even if their Working Memory is remembering the location of the tokens in the other containers. I will describe a task shortly (in section 3.4) which approximates to this, but it is carried out on young children. The use of younger subjects allows one to simulate this sort of situation, but strips away some of the more sophisticated aspects of the adult system which complicate the interpretation of a task such as this.

Representations are stored in the Current State Buffer if they are important to a given individual's current environment, and hence the contents of Current State Buffers are individual-specific. The crucial point though, is that these representations are distinct from other stimuli that are less important to an individual's current environment. Of course it is impossible to know the full contents of an individual's Current State Buffer, which may suggest that experimental manipulations concerned with the Current State Buffer are difficult to orchestrate. However, if the importance of a stimulus is systematically varied, then one should be able to influence whether or not its representation ends up in the Current State Buffer.

[22] As I am in fact suggesting in the examples given above.

3.3 Barreau and Morton's Bag Task

I have now motivated the idea of a Current State Buffer as an important component of Short Term Memory, and at least at the intuitive level, it seems to be a useful construct. The real test of a new construct however, is whether it can be fruitful on an experimental level. An example of an existing study that was designed on the basis of predictions made by the destructive updating characteristics of the Current State Buffer, is that of Barreau and Morton (submitted) . In their experiment, a manipulation was made on the "Smarties" experiment (Perner, Leekam and Wimmer, 1987), commonly done on 3- and 4-year-olds. In this classic paradigm, the child is shown a tube of Smarties and asked what is inside it, to which they usually respond "Smarties". They are then shown the true contents of the tube, namely pencils, and the lid is replaced. The child is then asked to say what is now in the tube, and they respond "pencils". However, about 75% of 3-year-olds fail to answer correctly what they thought was in the tube, and respond "pencils" to this question too. The 4-year-olds, however, have no problem with this, and respond, "Smarties". These results are usually explained within the "Theory of Mind" literature, as being due to some kind of competence deficit for the three year olds, for example an inability to represent a false belief (e.g. Perner et al., 1987).

Barreau and Morton enabled 3-year-olds to pass the tube task. The manipulation was to pour the contents of the tube (i.e. the pencils - although the child has not seen them at this stage) into a bag, after the child had been asked, "what is in the tube?". When the 3-year-olds are shown the contents of the bag, and are asked about what is in the bag, and what they thought was in the bag, 70% respond "pencils" to both questions (Gopnik and Astington, 1988). However, when the 3-year-old is then asked to say what they first thought was in the tube (which is then produced), 75% correctly respond "Smarties".

Introducing a Current State Buffer into a theory of Short Term Memory can help to explain why 3-year-olds fail the Smarties task. The theory was used to predict that they would succeed when the bag manipulation is appended, as in Barreau and Morton's experiment. The central assumption is that the child represents the tube and its contents (inferred or otherwise), in the Current State Buffer. This is because they are very much in the forefront of the child's attention. Thus when the children are first shown a Smarties tube, they form a representation of what they have interpreted from the environment around them - namely that there are Smarties in the tube. This is supported by their initial response when asked what they think is in the tube (they respond "Smarties"). When the true contents are revealed, the previous representation relating to the contents of the tube is destructively updated, and replaced with a representation of pencils in the tube, that relates to the new status of their immediate environment. Thus when the child is asked what they first thought was in the tube they are incorrect as this information had been wiped out, due to its transitory nature. For 4-year-olds, Barreau and Morton's account of information flow is exactly the same, but the capacity of their memory system is sufficient to compensate this limited capacity (see Barreau, 1997; Barreau and Morton, submitted).

The bag manipulation was employed to force the child to create a more permanent representation of the initial state. According to Morton, Hammersley and Bekerian (1985), permanent Records are laid down in Long Term Memory when there is a change of context. When the inferred contents of the tube are poured into the bag half way through the experiment, there is a change of context. The representation of the child's inferred belief about the contents of the tube that is first stored in the Current State Buffer is transferred into Long Term Memory. The Current State Buffer is then concerned with the contents of the bag, which falls victim to the same destructive updating effects suffered by the child in the original Smarties tube situation.

3.4 Independence of the Current State Buffer from Working Memory

Although the concept of a Current State Buffer had been invoked successfully in the Barreau and Morton (submitted) study, I felt that it was still necessary to actually demonstrate the existence of such a Buffer, independent of the existing specified components of Working Memory. This is what the first part of the empirical work of this thesis, in chapters four and five, aims to achieve. I will now outline the technique that I used to dissociate Working Memory from the Current State Buffer, notably a technique "borrowed" from Working Memory research - dual-task methodology.

The design involved a new paradigm, the "Tidy Emu Paradigm" used in all of the experiments presented in this thesis. The task comprised an Emu glove puppet (engineered by the experimenter) tidying away objects (toys) into receptacles (this activity is henceforth called pairing). The "story" presented to the children was that this Emu was particularly tidy (hence "Tidy Emu"), and therefore went about tidying things up. On seeing that some toys were left out in a mess, Emu was going to tidy them away into the receptacles on the table. The subjects were told to watch this carefully so that they would know where the toys were later on. The subjects were 3- and 4-year-olds, who were immediately probed for the locations of these objects, following the pairings.

This is a task that engages the Visuospatial Sketchpad, and will therefore have associated with it an age-related capacity.

This paradigm first facilitated a way of ascertaining Working Memory capacity (of the Visuospatial Sketchpad) for hidden objects in pre-school children in a pilot study. Once this capacity was established, the aim was to introduce another pairing that would overload this capacity beyond ceiling performance. Hence the addition of another pairing would cause interference. However, if this additional pairing engaged the Current State Buffer, then the capacity of the child to recall the additional pairing should show independence to the Working Memory component of the task, as indexed by a lack of interference with it. In this sense, the task employs dual-task methodology, which as I have noted in the preceding chapters, has been of vital importance in expanding the Working Memory literature and methodology.

Another way of explaining what the paradigm achieved, is to start by saying that the task ostensibly engages a child in a Working Memory task, specifically using the Visuospatial Sketchpad to code the location of toys in receptacles. A pilot study had revealed that 3-year-olds were pushed just beyond their Visuospatial Sketchpad capacity if they had to remember 3 pairings, and 4-year-olds if they had to remember 4 pairings. Hence if subjects had their Visuospatial Sketchpads occupied by having to remember 3 or 4 pairings (according to their age), one more pairing would introduce interference into their recall of the object locations. This would be because of their now heavily overloaded Visuospatial Sketchpads. However, if an extra pairing is added that engages the Current State Buffer instead, then interference with the items in the Visuospatial Sketchpad would be avoided because the extra pairing would be stored in a different place in the system. So a comparison of the performance of subjects' recall of pairings where the additional pairing was either another "Working Memory pairing", versus when it was a "Current State Buffer pairing" is critical. If the extra pairing results in interference with the other objects when it is a Working Memory pairing, but not when it is a Current State Buffer pairing, then it is reasonable to assume that Working Memory is separate from the Current State Buffer.

The critical manipulation through which the additional pairing engages either Working Memory or the Current State Buffer, is the final part of the description of the Tidy Emu Paradigm. Recall that there are toys that are hidden in various receptacles. If one of the toys is a small Teddy Bear (henceforth Teddy), then there is a possibility of making it a very important feature of the child's environment by instilling it with animacy, and getting the child to interact with it. This could then be contrasted with a condition where Teddy was just one of the toys on the table in front of the child. In both conditions, Teddy is an additional pairing and is placed in one of the receptacles. However, it is only when he is sufficiently important to be tracked by the Current State Buffer that this will offset interference with the other objects.

3.5 Choice of Subject Population and Task

The Tidy Emu Paradigm was a visuospatial task for pre-school children, and it was designed explicitly to demonstrate the independence of Working Memory from the Current State Buffer. The choice of a spatial task with pre-school children was made deliberately for three main reasons. First, it was crucial that the whereabouts of the representations for the pairings in the system could be confined to one place - the Visuospatial Sketchpad. As I have mentioned (e.g. section 1.3.3.4)., studies of visual Short Term Memory in adults have been confounded by problems stemming from the tendency for verbal memory codes to be used in visual tasks (Hitch et al., 1988). The use of pre-school children meant that visual-spatial representations of stimuli would stay in the Visuospatial Sketchpad. The second justification for choosing 3- and 4-year-olds as the sample is that the immature visual memory system is presumably simpler than the adult system, and presents a more tractable problem for investigation. The third argument for the choice of sample was that the age-group allowed optimum comparison with Barreau and Morton's study, which as noted before (in section 3.3), successfully invoked the concept of a Current State Buffer.

As I intimated at the close of Chapter 2 (in section 2.4.2), there have been very few visuospatial tasks documented for this age-group (e.g. Schumann-Hengsteler, 1992), and notably, these tasks were designed for slightly older children (e.g. de Ribaupierre and Bailleux; Walker et al., 1994). Nevertheless, the need for the Tidy Emu Paradigm was essentially motivated because these other tasks did not present themselves easily for a Current State Buffer/Working Memory dissociation. In other words, even if the task-specific capacity of an existing task was known, the manipulation to be made on an additional item for it to engage the Current State Buffer presented a difficult problem. In addition to these reasons for the design of a novel paradigm, the Tidy Emu Paradigm also allowed further investigation into issues related to the Current State Buffer, as should become apparent further on in the thesis.

3.6 Experiment 1

In Experiment 1 there were two conditions - *Character* and *Object* - referring to whether Teddy was an animate character or just another toy, respectively. The Character condition consisted of Emu tidying away objects into receptacles, with Teddy being an additional but animate character who goes to sleep in the same receptacle set. The Object condition consisted of the same number of objects being tidied away, but with Teddy as an additional (non-animate) object, who is tidied away with the rest of the toys. Teddy became animate by interacting with the subjects before the toys were tidied away, in a short episode which also included measuring the subjects' digit span. The 3-year-olds watched three objects plus Teddy being tidied away, and the 4-year-olds watched four object pairings plus Teddy.

The dependent variables of interest were whether subjects were correct on recall of Teddy's location and the object locations[23]. The hypothesis was that the location of Teddy would reside in the Current State Buffer in the Character condition, but in the Visuospatial Sketchpad in the Object condition. This would mean that there would be an extra load for Working Memory in the Object condition, resulting in interference with performance on recall of the location of the other objects. In the Character condition however, there would be no interference, as the location of Teddy would be registered in the Current State Buffer, leaving Working Memory performance untouched relative to subjects in the Object condition. Because the whereabouts within the system of the representation of Teddy would differ across conditions in this way, better performance was also predicted on memory for Teddy in the Character condition, relative to the Object condition.

These predictions were first tested in the experiment reported in the next chapter, although the predictions reflect a basic assumption that underpins the entire body of empirical work that I report in the thesis. This is that in the Tidy Emu Paradigm, subjects store the representation of the location of the objects and Teddy in different parts of the system in the Character condition, but that all the representations of the locations are stored in Working Memory in the Object condition.

[23] To avoid confusion, the dependent variable for the recall of object locations (objects) is differentiated from the Object condition by the latter being capitalised. Similarly, the Character condition is always capitalised in the same way, and discernible from the references to "character" locations, as in Teddy's location In Chapter 7, when more than one character is hidden, this particular distinction will become especially pertinent, and I will be consistent with this principle in capitalising *Character* when I refer to *one Character*, *two Character* and *three Character* conditions.

CHAPTER 4

The Independence of the Current State Buffer

4.1 Chapter Outline

This chapter contains the first section of empirical work presented in this thesis. Experiment 1 describes how the Tidy Emu Paradigm was employed to show the independence of the Current State Buffer from Working Memory. As I have already explained, the basic task was for children to remember in which receptacles Tidy Emu put various objects, including an additional pairing (Teddy) that either further burdened Working Memory, or engaged the Current State Buffer. The main finding in Experiment 1 was that memory for the location of Teddy did not interfere with recall of the locations of the other objects when Teddy was an animate character, tracked by the Current State Buffer. When Teddy was treated as another object, however, recall of his location did interfere with the recall of the locations of the other objects.

The second half of the chapter then considers alternative explanations that one might use to account for the set of results. Some are ruled out on purely theoretical grounds, but others generate the need to make slight changes to the design. These adaptations are realised in Experiment 2, which is then introduced within this context.

4.2 Experiment 1

4.2.1 Method

4.2.1.1 Design

There were 2 independent variables: (a) age of child (3- or 4-year-olds) {between subjects} (b) Teddy condition (Object - Teddy as Object, or Character - Teddy as Character) {between subjects}, and two dependent variables - (a) correctly remembering an object pairing (i.e. an object's location in its receptacle), and (b) correctly remembering Teddy's location.

I have hypothesised above that both memory for Teddy and memory for objects would be better in the Character condition relative to the Object condition.

4.2.1.2 Participants

The participants consisted of 3- and 4-year-old pre-school children from a number of local nurseries in North London, representing a cross section of varied economic status.

There were 28 of the 3-year-olds (2 in each of the 7 randomisations for the 2 conditions) and 28 of the 4-year-olds (2 in each of the 7 randomisations for the 2 conditions). The mean ages were 3;10 (range, 3;1 to 3;12) and 4;8 (range 4;0 to 4;10).

4.2.1.3 Apparatus

The apparatus consisted of 2 'characters' (or 1 was used in the Object condition), 4 'objects', and 7 'receptacles', which were manipulated on a desk.

The character that could be interchanged as an object was a small Teddy capable of fitting inside any of the receptacles. The other character was a glove puppet Emu that could easily manoeuvre objects with its beak. These two characters are pictured below in Photograph 4.1.

Photograph 4.1: Emu and Teddy

The objects were a toy car, three linked bricks of Lego, a plastic cat, and a crayon. The receptacles were a hat, a cup, a little box, a small bag, a sock, a plastic bowl, and a basket. Each of the objects could fit into any of the receptacles, thereby hiding them from the view of the child. This involved resting a patterned handkerchief over the top of each receptacle in the case of the cup, basket and bowl[24] (three differently patterned handkerchiefs were used for this).

The responses of the child were recorded by the experimenter on a specially prepared response sheet (see Appendix 4).

4.2.1.4 Procedure

1. Setting

Each child was run individually in a quiet room, with the child and experimenter sitting on nursery chairs at a nursery desk. The receptacles were randomly arranged for each experimental session along the horizontal, towards the back of the desk, and the objects were placed in a pile towards the front of the desk. Teddy featured as part of this pile in the Object condition, but was placed slightly to the side of them in the Character condition. Emu was kept out of the view of the subject at this stage of the experiment. The total number of objects used in each condition was dictated by the number of pairings that were to be tested, four for 3-year-olds, and five for 4-year-olds[25] (including Teddy). In the warm-up to the experiment, it was checked that each child knew the names of all the objects and receptacles. Where the child misnamed something

Photograph 4.2: Objects and receptacles on the table

The view seen by a 4-year-old subject at the start of the experiment. The receptacles are at the back of the desk, and the objects towards the front of the desk.

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[24] This did not cause extra confusions between these three receptacles. See comment in section 5.4.1.2.
[25]The number of pairings to be done by 3-and 4-year-olds had been explored in the pilot study, which established the basic pairing capacities of the 3-and 4-year-olds on the same task. The pilot study

(e.g. "pot" for the bowl), that name was then used to refer to that item when testing that child. Photograph 4.1 shows a (4-year-old's) subject-eye's view of the table and stimuli at this stage in the experimental proceedings.

2. Digit Span

In the Character condition, the first phase of the experiment required the experimenter to assess the children's digit span. In the Object condition this occurred in the final phase. The reason for this difference was that Teddy was used in an animate way in eliciting this measure in both conditions. Thus it was convenient for children in the Character condition to use this as an opportunity to "get to know Teddy" before the pairings. For these subjects, this contributed to establishing Teddy as an animate character at the point of his going to sleep.

To measure digit span, the child was told that Teddy was very popular and had lots of friends. In the Character condition, this was preceded by an introduction to Teddy ("we'll be playing a game with this fellow, he's called Teddy. Say hello to Teddy. These are Teddy's toys *(pointing to objects on table)*, and we'll be looking at them a bit later"). The child was then told that Teddy was so popular that he needed his own telephone and telephone line. The child was then asked to repeat his telephone number (specified slowly and clearly by the experimenter) which would be a 3 digit string excluding zero. The same string length was tested again with the child repeating Harry's number (one of Teddy's many friends). If two trials of the same string length were correctly repeated, then the string size was increased by one number (using other friend's numbers), and the procedure was repeated. If the child got one out of two strings correct at any length, a third, deciding, trial was given. The digit span was defined as the longest length at which children accurately repeated two trials with this procedure.

3. Teddy Sleeps

The next stage in the Character condition involved the experimenter commenting to the child that all of the toys (i.e. the objects at the front of the desk) belonged to Teddy, and that he had been playing with them all morning and so was very tired. Teddy then went off to sleep into one of the receptacles. In the Object condition, this phase was omitted.

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revealed that three pairings stretched 3-year-olds beyond ceiling performance, and four pairings stretched 4-year-olds beyond ceiling performance.

4. Emu

Immediately after this, the experimenter produced "Tidy Emu", and presented him to the child, who was encouraged to stroke the puppet, as depicted in Photograph 4.3.

Photograph 4.3: Meeting Tidy Emu

Image removed due to third party copyright

The subject was further informed that Tidy Emu didn't like mess, and had a habit of tidying things away. Emu was then seen to notice the toys that had been left in a mess, and the subject was told that Emu was going to tidy them up into the receptacles at the back of the desk, but that they had to remember where all the objects were so that they could be found later. In Photograph 4.4, Emu can be seen tidying away the objects while a subject watches carefully.

Photograph 4.4: Emu tidies away the mess

Image removed due to third party copyright

5. Pairings

The next stage varied according to the age of the child and the condition. For the Object condition, Emu placed each of the four toys (which included Teddy) in four different receptacles (3-year-olds), or each of the five toys in five separate receptacles (4-year-olds). In the Character condition, Emu placed three toys in three separate receptacles for 3-year-olds, and four for 4-year-olds. Note that Teddy was "tidied" first in the Object condition to match the fact that Teddy was always put to sleep first (and therefore paired first) in the Character conditions (and this also explains why there was one less object pairing relative to the Object condition in this phase of the experiment). On each pairing during this tidying phase, the experimenter instructed the child to watch carefully. The order of the pairings (and the objects and receptacles used) was dictated by the 7 different randomisations.

6. Testing of Objects' Locations

The test phase of the experiment was the same for both Teddy conditions. Immediately after the pairings had been completed, the child was tested for the location of the objects ("where is the cat?") directly by the experimenter (as opposed to role-playing Emu, who was placed out of sight from this stage forwards). The questioning was done in the same order in which the pairings had been made, except that Teddy's location was always asked for last. The children were encouraged to indicate the location of the objects with a verbal response, and were encouraged not to touch or point to the receptacle where they thought the object was concealed (they were told they could do this later). On the few occasions that they made no response or said they didn't know, the experimenter moved on to the next pairing. After recording subjects' responses in this way, the subjects were then instructed to actually find each of the objects in turn. For the subjects in the Object condition, when they found the Teddy, they were "introduced" to him and the same procedure to measure digit span as was employed with subjects in the Character condition was followed.

4.2.2 Results

For each child, the total number of correct responses was noted for the objects (excluding Teddy's pairing), along with whether or not they remembered the location of Teddy. Table 4.1 shows that every single child in the Character conditions, 3- and 4-year-olds, remembered the location of Teddy, whereas only half the children in the Object conditions recalled Teddy's whereabouts. These differences reached significance for each age-group on a Yates correct Chi Squared test (3-year-olds: $\chi^2 = 8.57$ (df = 1) $p < 0.003$; 4-year-olds $\chi^2 = 6.86$ (df = 1) $p < 0.009$).

The means and standard deviations of correct responses in each age-group for object locations (i.e. excluding Teddy) are shown in Table 4.2. Children in the Character condition seem to recall the toys' locations better than those in the Object condition.

TABLE 4.1 FREQUENCY OF RECALL OF TEDDY'S LOCATION IN EXPERIMENT 1

	3-year olds		4-year olds	
	Correct	**Incorrect**	**Correct**	**Incorrect**
Character	**14**	**0**	**14**	**0**
Object	**6**	**8**	**7**	**7**

TABLE 4.2 MEAN RECALL OF OBJECT LOCATIONS (EXCLUDING TEDDY) IN EXPERIMENT 1.

	3-year olds			4-year olds		
	Mean/3	**S.D.**	**n**	**Mean/4**	**S.D.**	**n**
Character	**2.00**	**1.1**	**14**	**2.71**	**1.06**	**14**
Object	**1.00**	**0.88**	**14**	**1.43**	**1.65**	**14**

Two-way ANOVAs were computed on the mean object location scores for both age groups with age and condition as between subject factors. This revealed a significant main effect of condition with $F_{(1,52)} = 12.46$, ($p < 0.001$). The main effect of age just failed to reach significance ($F_{(1,52)} = 3.12$, $p < 0.084$), and there was no interaction ($F_{(1,52)} = 0.66$; n.s.).

4.2.3 Discussion

Children in the Character condition performed significantly better than those in the Object group on both memory for objects and memory for Teddy. In fact, all children in the Character condition recalled Teddy's location correctly. This confirmed the first experimental hypothesis. According to this, children in the Character condition consistently recalled where Teddy was sleeping because Teddy had become an important character in the game and so his location was recorded automatically in the Current State Buffer. In the Object condition, Teddy was no more important than any of the other objects and so would be represented in Working Memory, and not in the Current State Buffer. Since Working Memory was already overloaded by the other pairings, memory for Teddy's location was worse for these children than for those in the Character condition.

Subjects in the Character condition exhibited better memory for objects (supporting the other half of the experimental hypothesis) for similar reasons. For them, Teddy's location was stored in the Current State Buffer. For children in the Object condition, Teddy's location was stored in Working Memory. In effect, these children in the Object condition had to store one more pairing than the children in the Character condition. Hence the subjects in the Object condition suffered interference from this extra pairing on their recall of the other object locations.

4.3 Other Explanations and Experiment 2

4.3.1 von Restorff Isolation Effect

An alternative interpretation of the results which needs some consideration is the possibility that better memory for Teddy in the Character condition is due to a *von Restorff Isolation Effect.* Simply put, this effect is the enhanced memory that is conferred by a distinctive item in an otherwise homogenous list (von Restorff, 1933). In the present study, the very fact that Teddy had become an important character for children in the Character condition, relative to the other toys, could be viewed in this way. Hence, the relatively worse memory for Teddy in the Object condition, where he was equivalent to the other items (objects) in the list.

Analysis of the von Restorff literature, however, reveals that the finding in this study cannot be attributed to a von Restorff Effect. In addition to the facilitation in memory for the distinctive item, there is a secondary effect on memory for the homogenous items within the "isolated" list. In most circumstances, the tradeoff against the boosted memory for the isolated item (the von Restorff Effect) is a decrease in memory for the homogenous items (Wallace, 1965). For example, in a study by Cimbalo, Nowak and Soderstrom (1981), notably a study with a similar memory task and sample to the present experiment, a von Restorff Effect was found with two age-groups of children. The children viewed cards of different line-drawn animals, presented successively, with the middle card coloured pink in the isolated condition (and not in the non-isolated list). After each card was presented, it was placed face-down in front of the child. When the last card was placed down the child was given the name of an animal and told to point at the relevant card (i.e. remember the 'location' of the animal). Recall of the isolated pink animal was superior to its line drawn equivalent in a non-isolated list - the von Restorff Effect . However, memory for the other animals in the isolated list (homogenous items) was worse when compared with memory for the homogenous items in the non-isolated list[26].

In the present study, however, if one attributed the better performance by the Character subjects in remembering the location of the "isolated" Teddy to a von Restorff Effect, then one would also predict the accompanying decrement in performance for other objects. Clearly the increase in performance by the Character group on correct object pairings (the "homogenous items") that was actually found, rules out the explanation of a von Restorff Effect.

4.3.2 Levels of Processing

Another possible explanation of the difference between performance on Teddy in the two conditions needs consideration. The superior performance in the Character condition may be attributable to a Levels of Processing Effect (Craick and Lockhart, 1972, and see section 1.2.3). The argument would be that because Teddy became an important character for subjects in the Character condition, this was tantamount to a deep Level of Processing. Subjects in the Object condition therefore, would not be expected to perform as well because they encoded Teddy in a more shallow fashion as it just featured as another toy.

Notwithstanding a number of other theoretical criticisms with the Levels of Processing theory (see Baddeley, 1978), it is still difficult to operationalise what might be meant in the present study by a deeper Level of Processing for Teddy's location. This is especially difficult because most Levels of Processing studies use word-lists that vary on a semantic-physical continuum. Similarly, it is not entirely clear how a Levels of Processing account would explain the difference in performance on object locations between the two groups[27]. However, it is still necessary to investigate whether the extant literature on the topic would predict a Levels of Processing Effect in the current design.

As previously mentioned, Levels of Processing Effects are usually evidenced experimentally with subjects learning word lists in either a deep (e.g. rating pleasantness or meaningfulness of words) or physical (e.g. searching for specific letters, such as vowels in a word) fashion. In a meta-analysis of these studies, Brown

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[26] von Restorff Effects are usually obtained with the isolated item in a central position (as in the Cimbalo et al.. (1981) experiment), but Hunt (1995) provides evidence that the effect can equally be obtained with the isolated item in the first serial position, as in the present study.

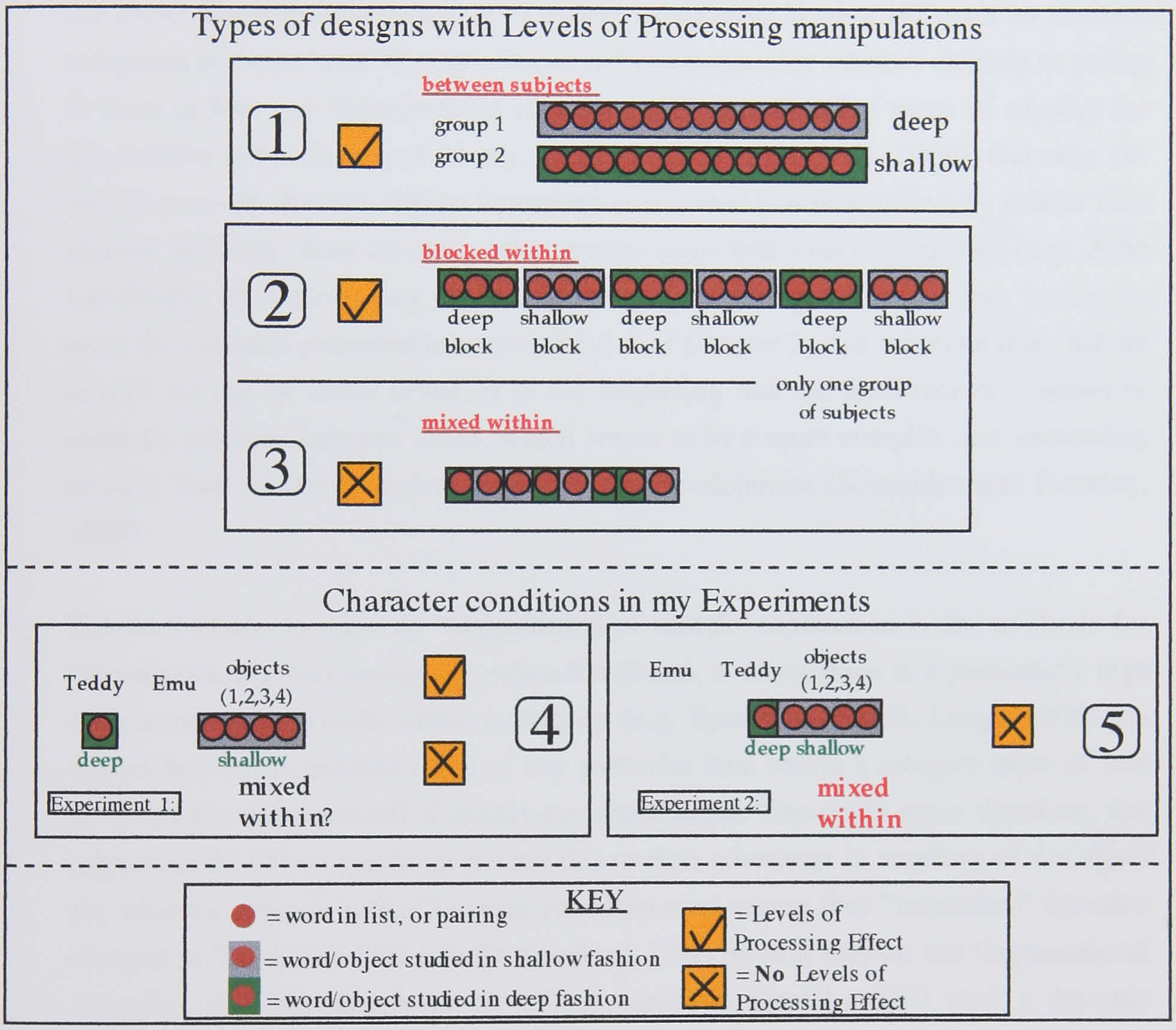
[27] Unless one contends that deep processing resources compete with shallow processing resources such that expenditure of deep encoding capacity encroaches upon shallow processing resources.

and Mitchell (1994) categorise the way in which the items are varied in processing depth as either *between* subjects or *within* subjects manipulations. A between subjects design is symbolized in box 1 of Figure 4.1, and would have one group of subjects exclusively encoding a given list of words in a deep fashion, and another learning the same list in a shallow manner. Within subjects designs, depicted in boxes 2 and 3 of Figure 4.1, use the same group of subjects, by varying the way that they process different lists of items and then comparing performance on these lists. Challis and Brodbeck (1992) further differentiate the way in which within subjects designs can be arranged. Within designs can either be *mixed* or *blocked*. In blocked-within designs, shown in box 2 of Figure 4.1, all subjects process a block of items semantically, and then another block of equal number shallowly (the order is not important). There are distinct "sessions" of differential processing ("shallow and deep blocks"). In mixed-within designs, portrayed in box 3 of Figure 4.1, subjects are instructed to process certain words in a deep way and others in a shallow way in one single "session" according to some predetermined signal for the type of processing required. Hence, in a mixed-within design, subjects are forced to alternate between semantic and non-semantic processing.

Challis and Brodbeck (1992) noted in their meta-analysis that Levels of Processing Effects can only be demonstrated using between designs and blocked-within designs, expressed in Figure 4.1 by the ticks in boxes 1 and 2. The mixed-within design does not produce Levels of Processing Effects, denoted by the cross in box 3 of Figure 4.1. The authors sought to confirm this by performing a Levels of Processing experiment which varied a between, a mixed-within and a blocked-within design. They found no Levels of Processing Effect when "deep" items were mixed together in one list with "shallow" items (a mixed-within subjects design). Either a between subjects, or blocked-within subjects design was found to be necessary for the effect, consistent with the results of their meta-analysis.

In the present study (expressed in box 4 of Figure 4.1), if Teddy featuring amongst the objects in the Character condition resembled a mixed-within subjects design, the Levels of Processing literature would not have predicted an advantage for Teddy, on the basis of the design itself. This was probably not the case, however, as it could be argued that Teddy's pairing in the Character condition, seconds before Emu had been presented and before the object pairings, served to make the design more "block-like". This uncertainty is expressed by having a cross and a tick in box 4 of Figure 4.1, effectively stating that while a Levels of Processing Effect may be predicted by the design, many other differences to standard Levels of Processing experiments exist. In Experiment 2 therefore (see Chapter 5), it was ensured that the objects were tidied away immediately after Teddy went to sleep. This was orchestrated by simply having Emu introduced to the subjects in the Character condition prior to Teddy sleeping. Thus as soon as Teddy went to sleep, the objects were tidied away by Emu. Hence the "deep block" is now juxtaposed to the "shallow block" in box 5 of Figure 4.1, and the tick now indicates that the Levels of Processing literature predicts no Levels of Processing Effect, since Experiment 2 constitutes a mixed-within subjects design.

Figure 4.1 Designs that may lead to Level of Processing Effects



4.3.3 Organisation of Stimuli

One may want to contend that the subjects in the Character condition of Experiment 1 were organising the objects into one "category" and the Teddy into another, whereas subjects in the Object condition were not able to categorise their "list" of stimuli in this way, as they were all objects. Consistent with many experiments on the effects of Organisation on word-lists, it would be predicted that recall of items in the organised list presented to subjects in the Character condition, would be superior (e.g. Bower, Clark, Lesgold and Winzenz, 1969) resulting in an increase in the performance on Teddy's location and on the object locations.[28]

First of all, it is debatable whether one can compare the Tidy Emu Paradigm to general studies of Organisation. Does just one item (Teddy as Character) form a separate category in the same way as there are separate categories with several exemplars per category in the Organisation literature? In addition, the type of Organisation involved in the above literature, consisting of semantic categories, is very different to the two categories of "toys " and "Teddy". Second, it is questionable whether children as young as three or four use Organisational strategies. A frequently cited piece of support for this inability is the finding of Moely, Olson, Halwes and Flavell (1969), that only 10- and 11-year-old children display Organisation at a level that is significantly greater than chance. Similarly, there are many other studies consistent with this position (e.g. Arlin and Brody, 1976; Cole, Gay, Glick and Sharp, 1971; Lange, 1973). In fact, bearing in mind the evidence presented in section 2.2.3.1 of Chapter 2, that rehearsal does not set in until the age of about seven, it is not surprising that the discovery or creation of semantic relations between items, which seems to be a more complex and demanding process than rehearsal, arrives even later in development (Schneider and Pressley, 1989).

The third reason to reject an "Organisation of stimuli" explanation is that evidence for Organisation at a very young age, when it is found, is where there is a particularly high association between items within a category (e.g. Bjorklund, 1985). Lange (1978) has argued that this is because recall of any particular item within a category more or less automatically triggers recall of closely associated items. One could argue therefore, that subjects in the Object condition can use this to their advantage in recalling all the object set, whereas subjects in the Character condition must ensure they "remember" the other category of Teddy in addition to the object set. Thus, even if they do use Organisational strategies, it is not clear why the Object condition should exhibit such a dramatic disadvantage to the Character condition.

Finally, a study by Axia and Caravaggi (1987) seems to argue against the possibility that the subjects in Experiment 1 were capable of semantic Organisation of the stimuli. In their study, they provide evidence that younger children (4-year-olds were the youngest group) are more sensitive than older ones to the spatial location of items than they are to semantic categories. Hence, if the subjects in Experiment 1 did perform any Organisation, they would have had a tendency to have done so on a purely spatial basis,

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[28] I am very grateful to Graham Hitch for suggesting this possibility to me.

and any of these effects would have been cancelled out due to the randomisations of the spatial layout of the stimuli and receptacles.

4.3.4 Intentional versus Incidental Learning

One of the more counterintuitive aspects of the superior performance of the Character group on recall of Teddy's location is the fact that children in this condition were not instructed to remember Teddy's whereabouts. Instead, they just passively watched Teddy go off to sleep in one of the receptacles. However, in the Object condition, children were told to remember where Teddy and all the other toys were being tidied as they would need to remember this for later. Relevant here therefore, is the distinction between intentional versus incidental learning (Greene, 1986). It could be claimed that the difference in performance on Teddy in the Character and Object conditions may simply be explained by the difference between an intentional (Object condition) and an incidental (Character condition) learning situation.

The validity of this claim can equally be checked by investigating existing empirical evidence. Neill, Beck, Bottalico and Molloy (1990) have shown that on an explicit memory test, anticipation of the test (i.e. intentional learning) actually facilitates learning relative to not anticipating a test. This would then have predicted better performance on Teddy for children in the Object condition who anticipated a test. In the present study, performance in recalling Teddy's location in the Character condition was facilitated even though this was learnt incidentally. This argues against the "intentional versus incidental" learning explanation for the results of Experiment 1.

4.3.5 Long Term Memory

Another possible argument against a Current State Buffer explanation is that Teddy's pairing in the Character condition may be seen as a separate event to that of the other object pairings. On the basis of the framework in Morton et al., (1985), the end of a Teddy event, signalled by his going to sleep, could trigger the creation of a Long Term Memory representation of what had just happened. If this were the case, then the independence of memory for Teddy and for the objects in the Character condition would reflect the difference between Short and Long Term Memory and not between Short Term (Working) memory and the Current State Buffer. In Experiment 2 therefore, Emu was introduced to the children prior to Teddy going to sleep, and immediately after he does go to sleep Emu tidies up all the objects. The immediate temporal proximity of the pairings of Teddy and objects in Experiment 2, would work against the creation of a separate event involving just Teddy's pairing.

4.3.6 Phonological Recoding

As stated in the introductory chapters (e.g. section 2.2.4.1), children of this age do not usually engage in the phonological coding of spatial information (Hitch et al., 1988). However, in the test phase of Experiment 1, children were encouraged to vocalise their responses of the locations (see section 4.2.1.4). Since this might have affected performance by engaging the Phonological Loop in some way in Experiment 1, children were instructed to point or to touch the receptacle when probed during the test phase in Experiment 2. In this way, I could be more confident that performance on the task would engage the Visuospatial Sketchpad exclusively.

4.3.7 Subject Confidence

One further issue is that the poorer performance of children in the Object condition might be because they have had less time than the children in the Character condition to become comfortable with the experimental situation.[29] Recall that, in Experiment 1, digit span was probed at the beginning of the experimental session for children in the Character condition, as a part of the crucial familiarisation with Teddy. In the Object condition however, children's digit span was measured at the end of the session, following the test-phase. A possible argument is that at the time of the test phase, children in the Character condition will be relatively more familiar and relaxed with the experimenter and the experimental set-up, possibly leading to better overall performance, relative to the Object condition. In Experiment 2, therefore, the time spent in the experimental situation prior to the pairings and testing in both conditions was controlled for, by introducing the digit span task at the beginning of the session for subjects in the Object condition. This was done by making use of a different character to Teddy to elicit digit span, since Teddy must feature as one of the toys, as in ExperimentÊ1. A completely new character, Simba, was introduced in Experiment 2 whose sole purpose was to probe digit span for subjects in the Object condition.

[29] I am grateful to Alan Baddeley for pointing out this possibility.

CHAPTER 5

Other Explanations

5.1 Chapter Outline

This chapter first describes Experiment 2, designed to rule out some of the alternative explanations to the data from Experiment 1, that were raised in the previous chapter. After successfully discounting these other explanations, I suggest that there are still further alternative accounts of the data. Experiment 3 is thus presented as a study that specifically addresses these remaining alternative explanations. The details of Experiment 3 then follow, and I argue that the results are best supported again by a Current State Buffer explanation. Thus these two further experiments replicate the findings of Experiment 1, and provide more evidence that the Current State Buffer is distinct from Working Memory.

5.2 Experiment 2

Let me recapitulate the changes made to Experiment 1 that were brought about in Experiment 2. First, I varied the order of events in the Character condition by

TABLE 5.1 SUMMARY OF EXPERIMENT 2 CONDITIONS.

Character2	Simba
1. Interaction with Teddy	1. Interaction with Simba
2. Naming objects and receptacles	2. Naming objects and receptacles. "objects" include Teddy
3. Introduced to Tidy Emu	
4. Teddy goes to sleep in a receptacle	4. Emu tidies away Teddy
5. Emu tidies away objects into receptacles	5. Emu tidies away objects into receptacles
6. Probed recall of location of objects	
7. Probed recall of location of Teddy	

presenting Emu to the children before Teddy went to sleep. In addition, all children were encouraged to point or to touch the appropriate receptacle when probed rather than say where the target was. Third, subjects in the new Object condition interacted with a baby lion called Simba in exactly the same way as subjects in the Character condition interacted with Teddy. A summary of Experiment 2 is sketched in Table 5.1. The new Object condition is called *Simba*, and the new Character condition, *Character2.*

5.2.1 Method

5.2.1.1 Design

The design was identical to that employed in Experiment 1. The conditions were renamed "Simba" - Teddy as Object, and "Character2" - Teddy as Character. As with Experiment 1, it was hypothesised that recall for Teddy's location and recall for the object locations would still be better for subjects in the Character2 condition relative to subjects in the Simba condition.

5.2.1.2 Participants

The children were 3- and 4-year-old pre-school children from a number of North London nurseries. No child had participated in Experiment 1. As with Experiment 1, there were 28 of the 4-year-olds (2 in each of the 7 randomisations for the 2 conditions), and 28 of the 3-year-olds (2 in each of the 7 randomisations for the 2 conditions). The mean ages were 3;7 (range, 3;2 to 3;12) and 4;5 (range 4;0 to 4;12).

5.2.1.3 Apparatus

The apparatus was identical to that employed in Experiment 1, with the addition of Simba, a baby lion, similar in size to Teddy. Simba is pictured in Photograph 5.1.

Photograph 5.1: Simba

5.2.1.4 Procedure

The procedure, outlined in Table 5.1, was similar to Experiment 1, but with one major alteration to *each* of the two conditions, and one change in the testing phase. The procedures before the testing stage for each condition will be dealt with separately. The testing phase - which was the same for both conditions - will then be described.

1. The Character2 Condition

The procedure was similar to that carried out in the Character condition in the first experiment, except that the order of events was changed slightly in order to remove the time gap between Teddy 'sleeping' and the objects being hidden. The first event involved Teddy being introduced and administering the digit span measurement (see section 4.2.1.4), following which the child named the toys and receptacles. Next, instead of Teddy going straight to sleep, as in Experiment 1, the child was told that Teddy was tired and that they would soon see what he would do next. Teddy was then placed to the side of the toys on the table. At this stage, Emu is presented, as in the previous experiment, with the same commentary. However, just before Emu begins to tidy the toys, the child is told that Teddy is going to sleep. Teddy was then placed by the experimenter in one of the receptacles as in the previous experiment. Immediately following this, Emu begins the pairings as in Experiment 1.

2. The Simba Condition

This condition was exactly the same as the Object condition in Experiment 1, except that before the naming of the toys and receptacles, the child is introduced to Simba. Subjects are told that Simba is very popular, and has so many friends that he needs his own telephone line. The digit span procedure, as carried out in the Character condition in Experiment 1, is then continued, but using Simba instead of Teddy. At the end of the digit span procedure, Simba is placed under the table, out of sight, "as he needs to go to sleep". This procedure equalised the amount of time children spent with the experimenter in the two conditions prior to the pairings. Emu is then presented as in Experiment 1, and the objects are tidied away. Subjects were asked at the end of the testing phase where Simba was.

3 Testing of Toys' Locations

The test phase was the same for both conditions in Experiment 2, but the instructions were slightly different from those in Experiment 1 in that subjects were told to touch or point to the relevant receptacles when probed, as opposed to being instructed to emit a vocal response. The order of probing the objects was the same as in Experiment 1, namely the objects were probed in the order of hiding, followed by probing Teddy. This can be represented by *123(4) Teddy.*

5.2.2 Results

The total number of correct responses for each child was collected (out of the number of objects paired excluding Teddy's pairing), along with whether or not the subject remembered the location of Teddy. Table 5.2 shows that all children in the Character2 conditions remembered the location of Teddy, compared with about half the children in the Simba conditions. Yates corrected Chi Squared tests were carried out to investigate whether there was a difference between the Character2 and Simba conditions for each of the age groups. Both tests yielded significant differences (3-year-olds $\chi^2 = 6.86$, df = 1, $p < 0.009$; 4-year-olds $\chi^2 = 3.9$, df = 1, $p < 0.05$).

TABLE 5.2 FREQUENCY OF RECALL OF TEDDY'S LOCATION IN EXPERIMENT 2

	3-year olds		4-year olds	
	Correct	**Incorrect**	**Correct**	**Incorrect**
Character2	**14**	**0**	**14**	**0**
Simba	**7**	**7**	**9**	**5**

The performance of children on object locations (i.e. excluding Teddy) are shown in Table 5.3. Subjects in the Character2 condition recall the toys' locations better than those in the Simba conditions. Two-way between subject ANOVAs were computed on the mean object location scores, revealing an effect of condition on the toys' locations $F_{(1,52)} = 5.65$, $p = 0.021$. There was no main effect due to age ($F_{(1,52)} = 2.29$, n.s.), and no interaction between age and condition ($F_{(1,52)} = 0$, n.s.).

TABLE 5.3 MEAN RECALL OF OBJECT LOCATIONS (EXCLUDING TEDDY) IN EXPERIMENT 2

	3-year olds			4-year olds		
	Mean/3	**S.D.**	**n**	**Mean/4**	**S.D.**	**n**
Character2	**2.21**	**0.97**	**14**	**2.71**	**1.38**	**14**
Simba	**1.43**	**1.22**	**14**	**1.93**	**1.33**	**14**

In the Simba condition, only two subjects (out of 28) failed to recall where Simba was at the end of the experiment.

5.3.3 Discussion

Children in the Character2 conditions performed significantly better than those in the Simba conditions both on memory for objects and on memory for Teddy. This replicated the findings in the first experiment. As before, these data were predicted on the basis of the function of the Current State Buffer. For children in the Character2 conditions, this Buffer would store the location of Teddy, allowing perfect recall, as Teddy had become an important character to these children. The children in the Simba group however, had to store Teddy's location in their Visuospatial Sketchpad and so suffered interference from their recall of the other objects. In addition, Character2 children had to store one less item in their Visuospatial Sketchpad, and so were able to perform better on the objects. Because the children did not produce any spoken responses when probed, the possibility of phonological re-coding is very slight, allowing one to suppose that the representation of the object locations would be held in the Visuospatial Sketchpad.

It is very probable that Simba was also tracked in the Current State Buffers of subjects who were in the Simba condition because, like Teddy in the Character2 condition, he had become an important stimulus. The reason why there was not perfect performance is probably because when Simba went to sleep he went to sleep under the desk which went away from the view of the subject. Whereas most subjects specifically tracked him going there, the two subjects who did not remember where he was may just have assumed that he "went away" and did not make an effort to notice where he actually went to sleep. In the Character conditions, there *is* perfect recall because Teddy goes to sleep in one of the receptacles directly in front of the subject.

The replication of the basic Current State Buffer dissociation, even after the alterations to the temporal order of Teddy's pairing in the Character2 conditions, make it difficult to posit that Teddy's location had been stored in Long Term Memory. Teddy's pairing occurred immediately before the other object pairings and therefore was unlikely to have become a separate event. For the same reason, it is difficult to posit that Teddy's increased recall in the Character2 condition was due to a deeper Level of Processing. The alterations to the design rule out a Levels of Processing account, as the design became a mixed-within (see section 4.3.2).

The claim that the difference in performance in Experiment 1 between the two groups can be accounted for by the difference in time spent in the experimental situation (see section 4.3.7) can also be ruled out. In the Simba conditions, children spent equally long in the experimental set-up before they observe the pairings and are tested on them. Nevertheless, the established difference in performance was still found.

5.3 Experiment 3

Experiments 1 and 2 seem to provide a set of results that are best explained by positing a Current State Buffer as distinct from Working Memory. However, there still remain two further possible explanations for the pattern of data. These are now introduced, and Experiment 3 tests predictions stemming from these possibilities.

5.3.1 Recency Effects

As I mentioned in Chapter 1, the notion of a Current State Buffer has some similarities to the way in which a construct is talked about by Baddeley and Hitch (1993; Baddeley, 1986). These authors invoke the ubiquitous *recency* effect to explain one's orientation in time and space. The recency effect refers to the increased memory performance for the last item (and sometimes items) in a list (Glanzer, 1972, and see section 1.2.2.2). Baddeley and Hitch's idea is that we possess recency effects for every aspect of our lives; we know what day it currently is, as it is the most recent; we know where we parked our car as it is the most recent place that we have parked our car, and so on. The implication is that one can have multiple recency effects for all types of event in our lives. As part of the support for this contention, a study by Watkins and Peynircioglu (1985) is cited, where multiple recency effects were found for different types of categories of items.

It is possible to argue that the results from Experiment 1 (and Experiment 2) can be explained along these lines. The argument would be that when Teddy is animated for the Character children, he forms a category of items[30] that is distinct from the other objects (Hitch, personal communication). The question of what criteria are necessary to create a separate category for multiple recency effects is in fact raised by Watkins & Peynircioglu (1985), and these authors have conceded that the boundary is unclear and that they needed to work very hard to design stimuli which gave rise to multiple recency effects[31]. For the sake of argument, however, one might assume that the Teddy manipulation is sufficient to create two separate categories of items in the Character condition; Teddy as one category and the objects as another. This would mean that the location of Teddy would have a distinct recency effect associated with it as a member of the category of significant objects. Therefore children in the Teddy as Character conditions would be expected to recall his location better than children in the Object

[30] It is important to note that with this multiple recency effect interpretation there are problems with the numbers of items in the categories. We do not know whether having just one item (Teddy) in one of the (multiple) categories, is equivalent to the equal number of items in each category that Watkins and Peynircioglu (1985) used in their experiment. Nevertheless, for the sake of argument, this simplifying assumption is made.

group for whom Teddy is just another object. In summary, recency effects would be expected for both Teddy-like and object-like items in the Character conditions, but there would be just one recency effect for object-like items in the Object condition.

The aim of Experiment 3 therefore was to assess this claim by inducing a recency effect when probing locations, and then compare the predictions of a multiple recency effect with that of the Current State Buffer effect. Recall that, in the first experiment, the objects were probed in the order in which they were hidden, meaning that the most recent object to be hidden was probed the last (excluding Teddy). In order to induce a recency effect, the order of probing was designed such that recency effects were maximised (these conditions are termed *Rec-Char* and *Rec-Simba*). Specifically, the order of probing proceeded in the reverse order of hiding, with the last object hidden being probed first and so on *((4)321,Teddy)*. The position of Teddy's hiding and probing was kept as it was in the first two experiments. This difference in the order of item probing is illustrated in Table 5.4 below, contrasting the order of probing for children in Experiment 3 with those in Experiments 1 and 2.

TABLE 5.4 ORDER OF OBJECT PROBING IN EXPERIMENTS 1-3

	Experiment number	items hidden	items probed
4-year-olds	***Experiments 1 and 2***	**T1234**	**1234T**
	Experiment 3	**T1234**	4321T
3-year-olds	***Experiments 1 and 2***	**T123**	**123T**
	Experiment 3	**T123**	321T

The nature of multiple recency effects is relevant to assessing this interpretation of the results. As stated above, Watkins and Peynircioglu (1985) produced multiple recency effects. In their study, they interwove three different categories of lists together into one long list, and tested for recall of each category. Their control condition consisted of subject just learning an equivalently-sized list of just one category. They documented that multiple recency effects resulted in the *lower* recall of the final ("recency") items by the subjects in the multiple category condition, compared with the recall of the final

[31] In divulging that they had failed to gain multiple recency effects with many other different types of categories, it could be argued that when they did achieve the effect, it was simply the result of a

items by the subjects who just learned a single category. In addition, the category that was cued first was better recalled. In the present study therefore, it will be important to investigate recency effects for the objects in the Rec-Simba condition. These approximate to a single category. Similarly, it is necessary to investigate the nature of the recency effects for both Teddy and the objects in the Character condition. This would approximate, in Baddeley and Hitch's terms, to a multiple recency effect.

If the findings in Experiment 1 were indeed simply attributable to a multiple recency effect, one would predict, from Watkins and Peynircioglu, that overall performance in the single category list (Rec-Simba condition) will be better than that of the multiple category list (Rec-Char condition). Next, recall that in Watkins and Peynircioglu (1985), the category which was cued first was better recalled. By analogy, this predicts that because the Teddy category is cued last in the Rec-Char condition, "recency" will be predicted to be lower than the final item of the object category, which is cued first. Under the theory of the Current State Buffer, I would predict the opposite result, a pattern similar to that found in Experiments 1 and 2, irrespective of recall order.

Based on the previous experiments, it is predicted that overall performance in the single category list (Rec-Simba condition) will be worse than that of the multiple category list (Rec-Char condition). Similarly, it is predicted that although the Teddy category is cued last in the multiple recency situation (Rec-Char condition), "recency" will be higher than the final item of the object category, that is cued first.

5.3.2 Teddy's Toys

Another possible problem with the results of Experiments 1 and 2, is that performance may be superior in the Character condition simply because the objects involved are presented as Teddy's toys (see section 4.2.1.4; "Digit Span"). The fact that in the Object and Simba conditions in Experiments 1 and 2 respectively, the objects do not belong to anyone in particular may have resulted in a relatively diminished performance in the recall of the items. The claim here is that the more meaningful schema of "Teddy's toys" confers an advantage on their subsequent processing. Therefore in Experiment 3, to equalise for this across conditions, children in the Simba condition are told that the toys belong to Simba. All other aspects, apart from the order of probing remain the same as in Experiment 2.

Type One Error.

5.3.3 Method

5.3.3.1 Design

The design was identical to that of Experiment 2. The only change was a re-naming of the two conditions that manipulated the nature of the extra pairing. The conditions were Recency Simba (Rec-Simba) - Teddy as Object, or Recency Character (Rec-Character) - Teddy as Character.

5.3.3.2 Participants

Individual participants were different to those used in Experiments 1 and 2, but also consisted of 3- and 4-year-old pre-school children from a number of local North London nurseries. As with former experiments there were 28 4-year-olds (2 in each of the 7 randomisations for the 2 conditions) and 28 3-year-olds (2 in each of the 7 randomisations for the 2 conditions). The mean ages were 3;7 (range 3;0 to 3;12) and 4;5 (range 4;4 to 4;12).

5.3.3.3 Apparatus

The apparatus was exactly the same as employed in Experiment 2.

5.3.3.4 Procedure

The procedure was identical to Experiment 2 apart from the order of testing for object locations. The order was the reverse order with respect to hiding (see Table 5.1)[32]. In addition, in the Rec-Simba condition, when Simba is introduced to the subjects, they are told that the toys belong to Simba, in the same way that they are told in the Rec-Char condition that they belong to Teddy. This "story" continues through the rest of the experiment for the subjects in the Rec-Simba condition, and so when Emu arrives, it is explained to subjects that Simba will need to know where his toys are and so they will have to watch carefully where Emu will hide them.

5.3.4 Results

The total number of correct responses for each participant was collected (out of the number of objects paired excluding Teddy's pairing), along with whether or not the participant remembered the location of Teddy. Table 5.5 shows that all children in the Rec-Char conditions remembered the location of Teddy, compared with less than half the children in the Rec-Simba conditions.

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[32] Teddy's location is probed after all the objects, as in Experiments 1 and 2.

Yates corrected Chi Squared tests were carried out to investigate whether there was a difference between the conditions for each of the age groups in Table 5.5. Both tests yielded significant differences (3-year-olds $\chi^2 = 10.48$ df = 1, $p < 0.002$; 4-year-olds $\chi^2 = 12.6$, df = 1, $p < 0.001$).

TABLE 5.5 FREQUENCY OF RECALL OF TEDDY'S LOCATION IN EXPERIMENT 3

	3-year olds		4-year olds	
	Correct	**Incorrect**	**Correct**	**Incorrect**
Rec-Char	**14**	**0**	**14**	**0**
Rec-Simba	**5**	**9**	**4**	**10**

The means and standard deviations of correct responses in both age groups for object locations are shown in Table 5.6. Subjects in the Rec-Char conditions recall the toys' locations better than those in the Rec-Simba conditions. A two-way ANOVA revealed a significant effect of condition on recall of the toys' location ($F_{(1,52)} = 7.03$, $p = 0.039$). There was a main effect due to age ($F_{(1,52)} = 4.50$, $p = 0.039$), and no interaction between age and condition ($F_{(1,52)} = 0.28$, n.s.).

TABLE 5.6 MEAN RECALL OF OBJECT LOCATIONS (EXCLUDING TEDDY) IN EXPERIMENT 3.

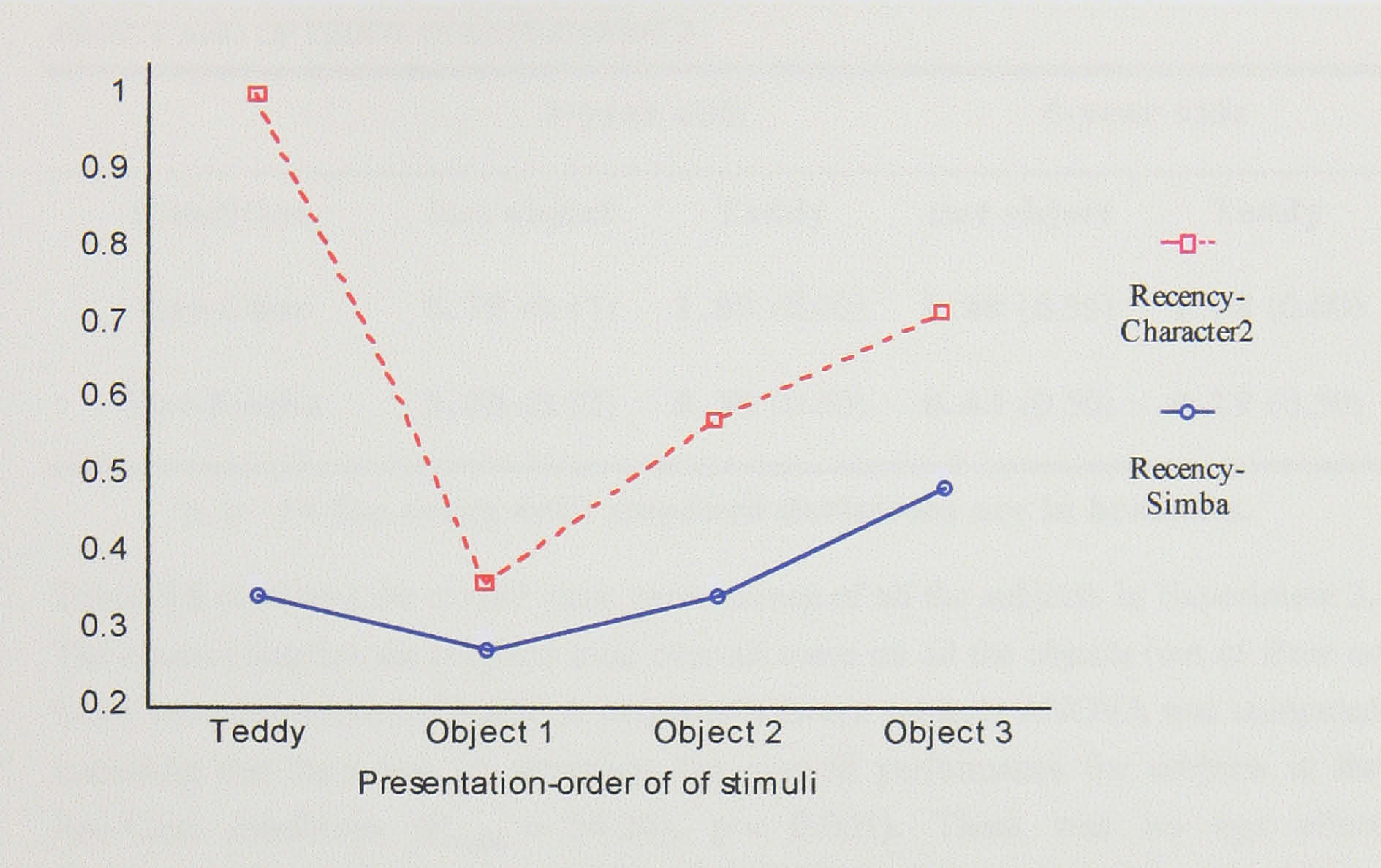
	3-year olds			4-year olds		
	Mean/3	**S.D.**	**n**	**Mean/4**	**S.D.**	**n**
Rec-Char	**1.64**	**1.01**	**14**	**2.36**	**1.15**	**14**
Rec-Simba	**1.07**	**1.0**	**14**	**1.5**	**1.85**	**14**

5.3.4.1 Recency

Mean correct responses were plotted as a function of item presentation order, for the two conditions below in Figure 5.1 (3-year-olds) and Figure 5.2 (4-year-olds).

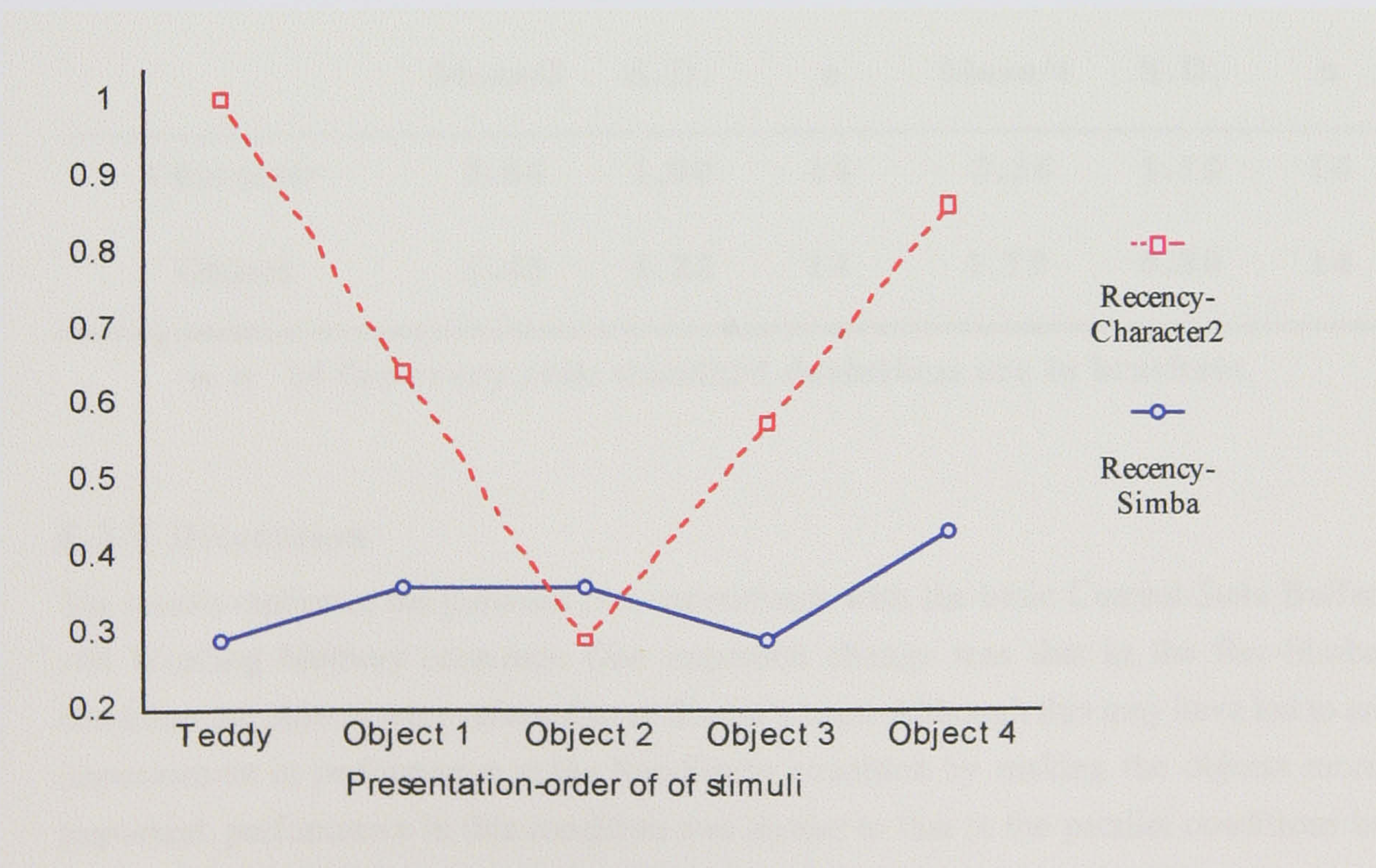
The mean correct recall of the final (recency) item of both conditions for both age groups was compared with the mean probability correct recall of Teddy, presented in Table 5.7.

Figure 5.1 Probability of correct recall on items according to item presentation order in Experiment 3 (3-year-olds)



Recall order was *321T*.

Figure 5.2 Probability of correct recall on items according to item presentation order in Experiment 3 (4-year-olds)



Recall order was *4321T*.

TABLE 5.7 MEAN CORRECT PROBABILITY OF RECALL OF THE MOST RECENT OBJECT AND OF TEDDY IN EXPERIMENT 3

	3-year olds		4-year olds	
Condition	**last object**	**Teddy**	**last object**	**Teddy**
Rec-Char	**0.70** (0.47)	**1.00** (0.00)	**0.80** (0.36)	**1.00** (0.00)
Rec-Simba	**0.50** (0.52)	**0.30** (0.50)	**0.43** (0.50)	**0.29** (0.50)

n = 14 for every cell; standard deviations are in brackets.

Table 5.8 compares the overall mean performance of all the subjects in Experiment 3. The means comprise the subjects' total over-all score on all the objects (out of three or four), plus their score on Teddy. A two-way between subjects ANOVA was computed indicating that there was an advantage for over-all performance for subjects in the Rec-Char conditions ($F_{(1,52)}$ = 24.26), p = 0.001). There was no age effect ($F_{(1,52)}$ = 3.59, n.s.) or interaction ($F_{(1,52)}$ = 0.40), n.s.).

TABLE 5.8 MEAN OVER-ALL PROBABILITY OF RECALL OF THE LOCATION OF ALL ITEMS FOR CHILDREN IN EXPERIMENT 3

	3-year olds			4-year olds		
	Mean/3	**S.D.**	**n**	**Mean/4**	**S.D.**	**n**
Character	**2.64**	**1.00**	**14**	**3.36**	**1.15**	**14**
Object	**1.43**	**1.22**	**14**	**1.79**	**0.80**	**14**

n = 14 for every cell; standard deviations are in brackets.

5.3.5 Discussion

The results replicated the previous two experiments with the basic Current State Buffer and Working Memory contrasts. One important change was that in the Rec-Simba condition the objects were referred to as Simba's toys. Although this may have led to an improvement in performance in the Rec-Simba condition by making the objects more important, performance in this condition was similar to that in the parallel conditions in the first two experiments.

The results also displayed recency effects for the objects, as indexed by an increase in memory for the final item (final with respect to presentation order - but actually the first item to be probed), as is clearly shown in Figures 5.1 and 5.2. Although Teddy's location in the Rec-Character condition was probed last, performance was better than on the recency item of the toys (as is evident from Table 5.7). This goes against the prediction based on Watkins and Peynircioglu (1985), and suggests that the increased performance on the recall of Teddy's location by subjects in the Character condition does not have anything to do with recency effects. This is further strengthened by the finding that overall performance was worse in the "one category" recency condition of the Rec-Simba children, whereas Watkins and Peynircioglu (1985) would predict that the subjects in the "multiple recency" condition of the Rec-Character condition would have worse performance.

5.4 Overview of Results of Experiments 1, 2 and 3

In Table 5.9 I summarise the data from all three experiments on recall of objects. A three-way between subjects ANOVA on this data (factors: age, condition and Experiment) showed a significant effect of age ($F_{(1,156)} = 9.41$, $p < 0.001$) and of condition ($F_{(1,156)} = 24.36$, $p < 0.001$) but no effect of Experiment ($F_{(1,156)} = 1.99$, n.s.) and no significant interactions. Planned comparisons within the separate age-groups revealed significant differences between the Character and Object conditions for both (3-year-olds $F_{(1,156)} = 9.69$, $p < 0.002$) and 4-year-olds ($F_{(1,156)} = 14.96$, $p < 0.001$).

TABLE 5.9 MEAN RECALL OF OBJECT LOCATIONS IN THE TWO EXPERIMENTAL CONDITIONS OF EXPERIMENTS 1, 2 AND 3

	3-year olds		4-year olds	
Experiment	**Character**	**Object**	**Character**	**Object**
1	2.00	1.00	2.71	1.43
2	2.21	1.43	2.71	1.93
3	1.64	1.07	2.36	1.50

5.4.1 Item Analyses

The next two sub-sections summarise the probability recall of the individual stimuli used in the first three experiments. I check that there are no differences between the three experiments in the recall of the individual toys (apart from Teddy in the Character conditions, of course) and receptacles.

5.4.1.1 Toys

TABLE 5.10 TOY PROBABILITY RECALL OF THE 3-YEAR-OLDS IN THE FIRST THREE EXPERIMENTS

	Experiment 1		Experiment 2		Experiment 3		All 3 Experiments		
	Obj	**Ch**	**Obj**	**Ch**	**Obj**	**Ch**	**Obj**	**Ch**	**both**
car	**0.36**	**0.57**	**0.43**	**0.64**	**0.36**	**0.57**	**0.38**	**0.62**	**0.50**
cat	**0.21**	**0.71**	**0.50**	**0.79**	**0.36**	**0.50**	**0.36**	**0.67**	**0.51**
crayon	**0.43**	**0.71**	**0.50**	**0.79**	**0.36**	**0.57**	**0.43**	**0.69**	**0.56**
Teddy	**0.43**	**1.0**	**0.50**	**1.0**	**0.36**	**1.0**	**0.43**	**1.0**	**0.71**

TABLE 5.11 TOY PROBABILITY RECALL OF THE 4-YEAR-OLDS IN THE FIRST THREE EXPERIMENTS

	Experiment 1		Experiment 2		Experiment 3		All 3 Experiments		
	Obj	**Ch**	**Obj**	**Ch**	**Obj**	**Ch**	**Obj**	**Ch**	**both**
car	**0.29**	**0.64**	**0.43**	**0.64**	**0.43**	**0.86**	**0.38**	**0.71**	**0.54**
cat	**0.36**	**0.86**	**0.57**	**0.79**	**0.50**	**0.57**	**0.48**	**0.74**	**0.61**
crayon	**0.43**	**0.50**	**0.36**	**0.57**	**0.36**	**0.43**	**0.38**	**0.50**	**0.44**
Lego	**0.36**	**0.71**	**0.58**	**0.71**	**0.21**	**0.50**	**0.38**	**0.64**	**0.51**
Teddy	**0.50**	**1.0**	**0.64**	**1.0**	**0.29**	**1.0**	**0.48**	**1.0**	**0.74**

Table 5.10 sets out the probability recall of the 3-year-olds in the first three experiments, and Table 5.11 displays this for the 4-year-olds. For each experiment there are two conditions; for simplicity they are called *Obj* for the Teddy as Object conditions, and *Ch* for the Teddy as Character conditions. There is also a probability figure for the overall probability recall for each of the toys across all three experiments

divided into separate conditions, and grouped across both conditions *(both)*. Note that Character conditions consistently have a higher recall over the Object conditions for all the toys.

a. The 3-Year-Olds

For the 3-year-olds, separate two-way split-plot ANOVAs with Experiment (1, 2, 3) as a between subjects factor and the toys as repeated measures, were conducted on the probability recalls for the two separate conditions (Obj and Ch). This was done so as to check that there was no variation on separate toy recall between experiments within the Object and Character conditions (there would be no point comparing the toy probabilities across conditions, as the Character conditions would generally perform better on all the toys - this analysis was just concerned with the recall of individual toys across the three experiments).

For the Object conditions, the analysis showed no effects of Experiment ($F_{(2,39)} < 1$ n.s.) or toys ($F_{(3,117)} < 1$ n.s.) and there was no interaction ($F_{(6,117)} < 1$ n.s.). As a result of the effects of the increase in recall of Teddy, however, there was a main effect of toys in the Character conditions ($F_{(3,117)} = 10.1$, $p < 0.000$). There was no effect of Experiment ($F_{(2,39)} < 1$ n.s.) nor was there an interaction ($F_{(6,117)} < 1$ n.s.) in the Character conditions.

b. The 4-Year-Olds

The same ANOVA model was conducted on the 4-year-olds. The same pattern emerged with a significant effects of toys in the Character condition ($F_{(4,156)} = 11.2$ $p < 0.000$), but no effect of Experiment ($F_{(2,39)} < 1$ n.s.), and no interaction ($F_{(8,156)} < 1$ n.s.). Similarly there were no effects in the Object conditions (toys: $F_{(4,156)} < 1$ n.s.; Experiment: $F_{(2,39)} < 1$ n.s; interaction: $F_{(8,156)} < 1$ n.s).

5.4.1.2 Receptacles

Table 5.12 below sets out the probability recall of the 3-year-olds in the first three experiments, and Table 5.13 displays this for the 4-year-olds. As with the above tables, for each experiment there are two conditions and a probability for the overall probabilities of recall across all three experiments; separate for the two conditions (Obj and Ch) and combined across them (both). Note that with the exception of three cells in the tables, the subjects in the Character conditions consistently have a higher recall associated with all the receptacles compared to the subjects in the Object conditions.

TABLE 5.12. RECEPTACLE PROBABILITY RECALL OF THE 3-YEAR-OLDS IN THE FIRST THREE EXPERIMENTS

	Experiment 1		Experiment 2		Experiment 3		All 3 Experiments		
	Obj	Ch	Obj	Ch	Obj	Ch	Obj	Ch	both
bag	0.25	0.50	0.25	0.88	0.50	0.75	0.33	0.71	0.52
basket	0.13	0.75	0.38	0.75	0.25	0.75	0.25	0.75	0.50
bowl	0.38	0.75	0.50	0.75	0.50	0.75	0.46	0.75	0.60
box	0.50	0.63	0.88	0.63	0.38	0.88	0.59	0.71	0.65
cup	0.25	0.88	0.75	0.88	0.38	0.50	0.46	0.75	0.60
hat	0.38	1.0	0.25	0.88	0.25	0.63	0.29	0.83	0.56
sock	0.63	0.75	0.38	0.75	0.38	0.38	0.46	0.63	0.54

TABLE 5.13 RECEPTACLE PROBABILITY RECALL OF THE 4-YEAR-OLDS IN THE FIRST THREE EXPERIMENTS.

	Experiment 1		Experiment 2		Experiment 3		All 3 Experiments		
	Obj	Ch	Obj	Ch	Obj	Ch	Obj	Ch	both
bag	0.40	0.60	0.20	0.60	0.10	0.50	0.23	0.57	0.40
basket	0.40	0.70	0.70	0.60	0.30	0.70	0.47	0.67	0.57
bowl	0.60	1.0	0.60	0.80	0.40	0.90	0.53	0.90	0.72
box	0.30	0.70	0.60	0.90	0.40	0.70	0.43	0.77	0.60
cup	0.50	0.90	0.60	1.0	0.30	0.50	0.47	0.80	0.63
hat	0.20	0.60	0.70	0.60	0.50	0.80	0.47	0.67	0.57
sock	0.30	0.70	0.30	0.70	0.40	0.60	0.33	0.67	0.50

Two ANOVAs on the receptacles' probability recall were computed for each of the two age-groups, with Experiment (1, 2, 3) as a between subjects factor, and the seven receptacles as within subjects factors.

a. The 3-Year-Olds

For the 3-year-olds, the analysis showed no effects of Experiment ($F_{(2,45)} < 1$ n.s.) or receptacles ($F_{(6,270)} = 2.15$ n.s.), nor any interaction between them ($F_{(12,270)} < 1.6$ n.s.). This implied that none of the receptacles were better recalled than any other for the 3-year-olds. Hence the possibility that the handkerchiefs placed over the cup, basket and bowl lead to confusions between these items, can be rejected.

b. The 4-Year-Olds

The analysis on the 4-year-olds' performance showed no effect of Experiment ($F_{(2,57)} < 1$ n.s.). However, there was an effect of receptacles ($F_{(6,342)} = 4.32$ sig. $p < .0004$), but no interaction between Experiment and receptacles ($F_{(12,342)} < 1.8$ n.s.). This implied that there was a difference in the way that this age-group of subjects recalled the various receptacles (as opposed to the 3-year-old, who did not display this pattern). The fact that the three receptacles that were associated with the highest probability recall, were the ones that had handkerchiefs placed over them, ruled out the possibility that the handkerchiefs had lead to confusions between these receptacles. The different probability recall scores across all the different receptacles does not have a readily interpretable pattern. One possibility is that some receptacles offer stronger affordances to the subjects, from experience, for holding objects than other receptacles (and the ability to appreciate this is follows a developmental path, whereby older children are more able to do so). At first glance, this trend seems to be consistent, since the hat and the sock have low recall probabilities associated with them, and of all the items, objects are generally less likely to be placed in these items However, the fact that the bag - a very common receptacle for all types of objects - had the *lowest* probability recall of all the receptacles makes this suggestion less tenable.

5.5 Conclusion to Chapters 4 and 5

My starting point in Chapter 3 was the proposal that the representations of important features of the environment are tracked by a separate component to Working Memory termed the Current State Buffer. In Experiments 1, 2 and 3, I have shown that memory for the location of a character with whom children have engaged is independent of memory for the location of other objects. In theoretical terms, I have concluded that the Current State Buffer is distinct from the Visuospatial Sketchpad component of Baddeley & Hitch's (1993) current Working Memory model.

I have considered the possibility that the data could be accounted for on the basis of the von Restorff Isolation Effect (section 4.3.1), Levels of Processing (section 4.3.2), the effects of Organisation (section 4.3.3), or in terms of incidental versus intentional learning (section 4.3.4). These were ruled out since the basic pattern of data in the present experiments simply does not correspond to that found in the relevant literature on these topics. I also considered the data as a phenomenon involving an autobiographical memory record (section 4.3.5) and in terms of a generalised recency effect (section 5.3.1), along the lines of Baddeley and Hitch (1993). The modifications in procedure I introduced to Experiments 2 and 3 make these accounts relatively implausible, compared with the simple account based on the Current State Buffer.

Now that the Current State Buffer has been established as independent from Working Memory, both the architecture of a system that would house such a component, and the nature of the component need to be explored. The remainder of this thesis attempts to achieve both of these aims through further use of the Tidy Emu Paradigm.

CHAPTER 6

Model Testing

6.1 Chapter Outline

In the last two chapters, the independence of the Current State Buffer from Working Memory has been demonstrated through the use of the Tidy Emu Paradigm. Having done so, the focus of this thesis now moves on to examine the nature of the Current State Buffer. The aim of the present chapter is to utilise further the Tidy Emu Paradigm to explore the architecture of a memory system that features a Current State Buffer.

A total of four experiments are reported in the chapter, and they all employ the Teddy as Character condition of the Tidy Emu Paradigm. However, the input and output order of the object and Teddy locations are varied. The rationale behind the chapter is first to consider versions of possible architectures (models) by which the data from the previous chapters can be supported Once this has been done, hypotheses can be generated based on these possibilities that will help to decide between the models. Finally the experiments are carried out, to test among these alternatives.

6.2 Possible Architectures

6.2.1 Introduction

Let me recapitulate the account so far of what happens for subjects in the Tidy Emu Paradigm. When subjects are instructed to observe the objects being tidied into the receptacles, the theory is that the object locations are stored in the Visuospatial Sketchpad. If a subject is in the Object condition, then the representation of Teddy's location will also be registered in the Visuospatial Sketchpad along with the other object locations.

When the child has interacted with Teddy in the Character condition, however, this has established Teddy as a "character", and thus the location (and mental state if the child is sufficiently capable) of Teddy is registered in the Current State Buffer. When Teddy then goes to sleep, his location is stored separately from the locations of the objects, which according to the hypothesis are located in the Visuospatial Sketchpad of Working Memory. Note that his location is stored, even though the children in this condition are not actually asked to remember where he goes to sleep.

For the moment, I shall simplify matters by referring to Working Memory as the *Interpreter Buffer*, in line with Barreau (1997). The rules for maintaining items in the Current State Buffer are unclear at present since only one item, namely Teddy, has been tracked by the Current State Buffer in the current design.[33] Given that every subject in the Character conditions remembered where Teddy was sleeping, the data suggests that when there is one item in the Current State Buffer, the information seems to be protected and maintained.

6.2.1.1 Architectures Supported by the Existing Data Set

A simple architecture that supports the existing data has input flowing into an input buffer that constructs an image of the current world (the *Environmental Buffer*). Then, depending on its status, representations of stimuli proceed to either the Interpreter Buffer (Working Memory) or to the Current State Buffer for short term storage. Representations are then output from these two components

There are two important issues here that dictate the gross structure of this architecture: firstly, the nature of the output, and secondly, the placement of the Current State Buffer relative to the Interpreter Buffer. These issues will now be dealt with in turn before an explicit structure of the system can be sketched.

1. Output from the System

In Barreau's (1997) "Trucks" experiment, pre-school children watched an event involving the exchange of contents between two toy trucks, and they were asked questions about initial and final states of the contents of the trucks. Barreau (1997) observed that the order in which questions were presented determined the availability of items for recall, with different orders leading to loss of different items of information.

Central to her explanation for this finding was that at output, all information flows through the Interpreter Buffer. Hence if there are any items being stored in the Interpreter Buffer, then their recall suffers interference if the retrieval of information from other parts of the system occurs prior to when items are being output. On the other hand, if the items in the Interpreter Buffer are probed first, then this change in question order allows these items to be recalled without interference. With this order of output, no other items have had to pass through the Interpreter Buffer and interfere with its contents, so both the items stored in the Interpreter Buffer, and the items in another part of the system are output successfully.

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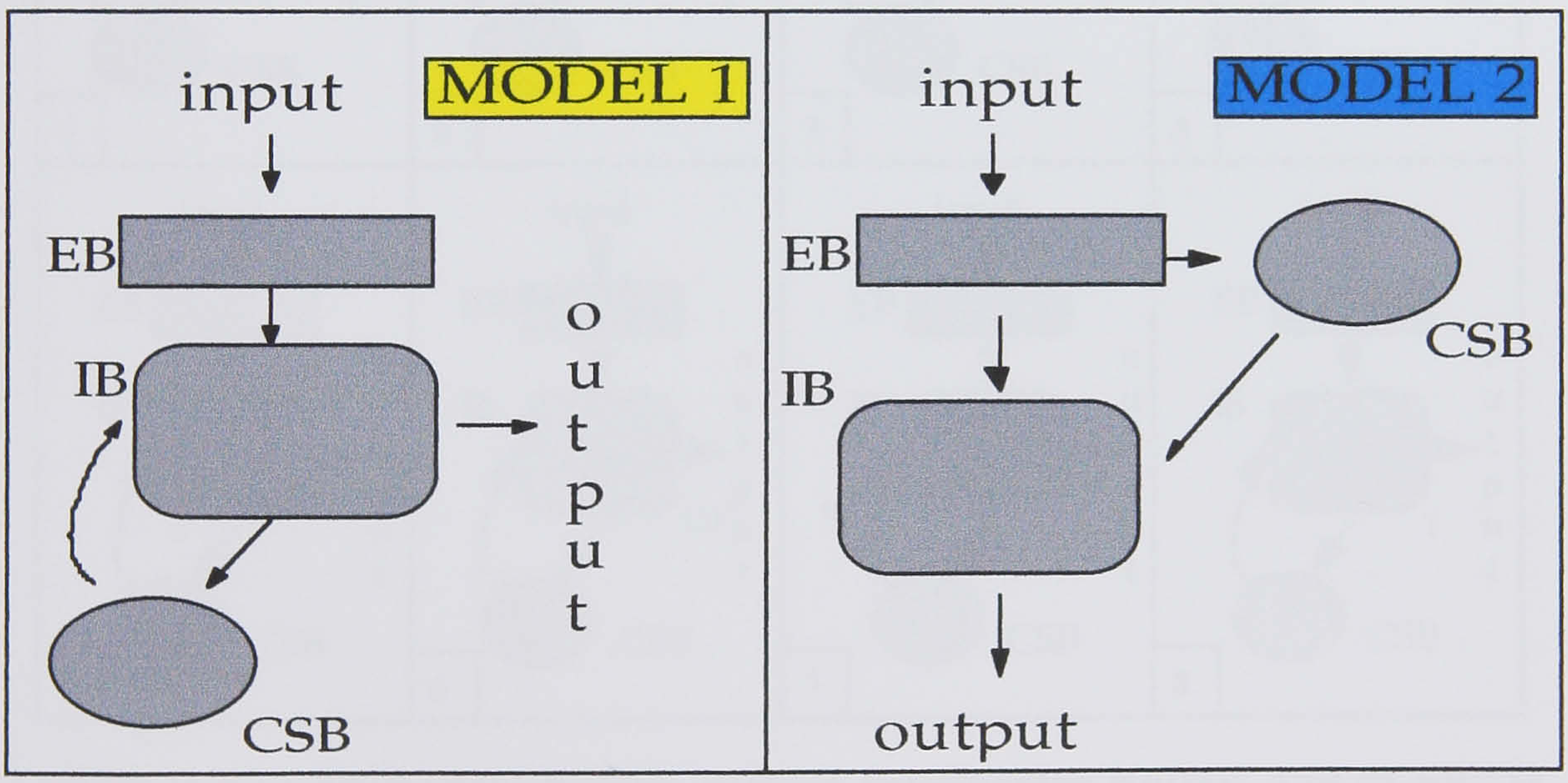
[33] The next chapter investigates this issue when multiple characters are tracked by the Current State Buffer in a standard Tidy Emu Paradigm.

In terms of the output in the simple architecture posited here therefore, consistent with the Trucks experiment it is assumed here that output flows directly out of the Interpreter Buffer if it is already being stored there. Similarly, if representations from other parts of the system (e.g. the Current State Buffer) are retrieved, then they proceed through the Interpreter Buffer as they are output from the system.

2. The Position of the Current State Buffer relative to the Interpreter Buffer

The essential question here is the path followed by sensory input after entering the Environmental Buffer. One possibility is that all representations pass straight into the Interpreter Buffer and then depending on their status into the Current State Buffer. The alternative is that this "decision" is made at the stage of the Environmental Buffer, passing "characters" into the Current State Buffer for tracking and "objects" to the Interpreter Buffer for storing. Both of these possibilities are viable for explaining the existing data set, and models with both of these structures will now be examined. The importance of having these two possibilities is that each Model predicts a different set of results. *Model 1* is the name given to the arrangement whereby Current State Buffer representations must pass through the Interpreter Buffer on input, and *Model 2* is where these representations pass directly into the Current State Buffer from the Environmental Buffer at input. These two models are depicted below in Figure 6.1

Figure 6.1 Model 1 and Model 2



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, and "CSB" is Current State Buffer.

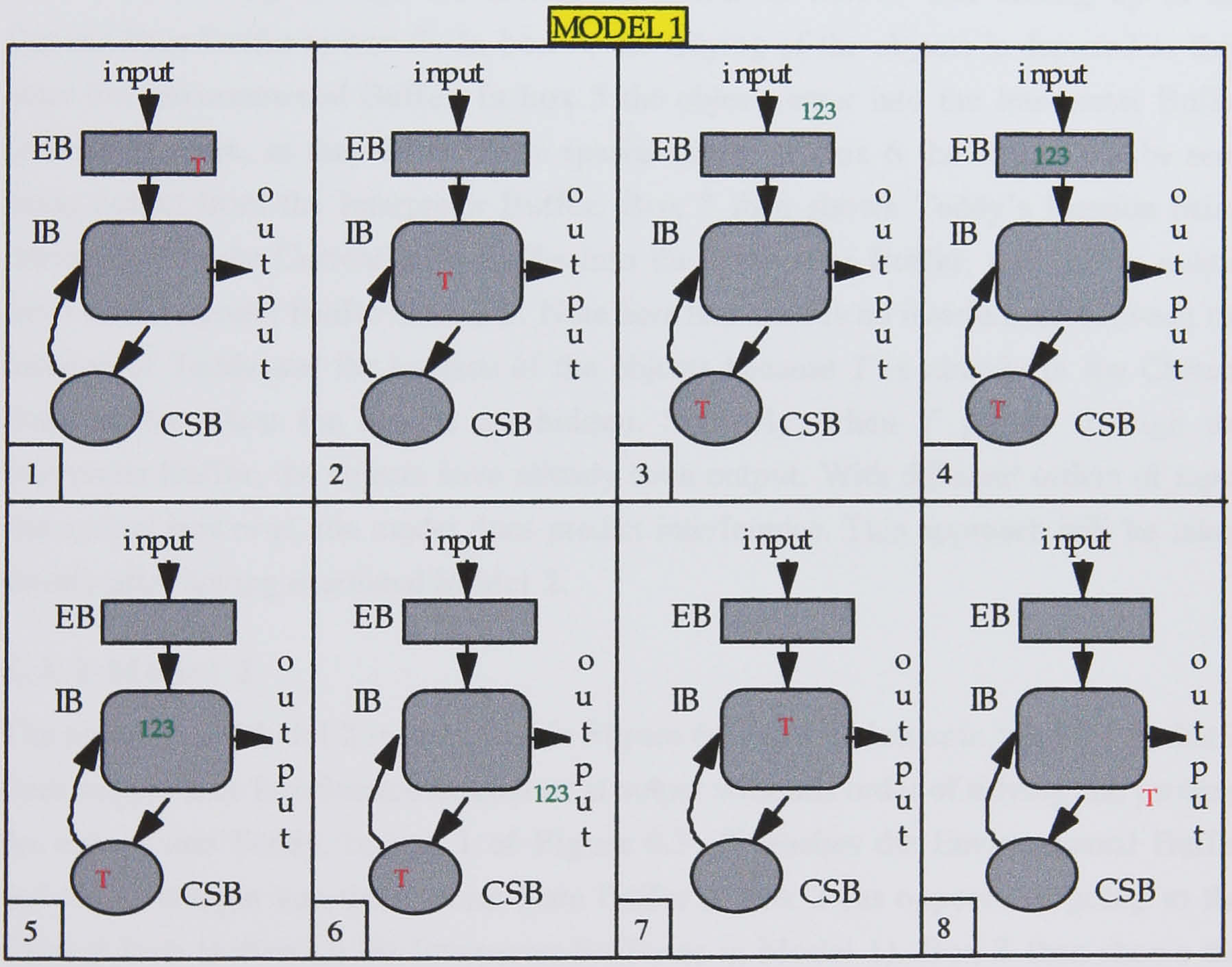
Both Models 1 and 2 can accommodate the findings from the first set of experiments by making certain simple assumptions about what goes on in the Tidy Emu Paradigm. Firstly, when interacting with the child a the start of the experiment, a representation of

Teddy together with his location enters the system at the Environmental Buffer and passes into the Current State Buffer, either via the Interpreter Buffer or directly from the Environmental Buffer. When hidden, the revised representation of Teddy in the new location is stored in the Current State Buffer, while the Environmental Buffer passes the representation of the object locations to be stored in the Interpreter Buffer. When the locations are probed, the representation of the object locations are directly output from the Interpreter Buffer, whereas the location of Teddy in the Current State Buffer passes through the Interpreter Buffer at output.

6.3 How the Two Models Explain the Existing Data Set

6.3.1 Model 1

Figure 6.2 How Model 1 explains Experiments 1, 2 and 3 *(T123 123T)*



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, and "CSB" is Current State Buffer.

Figure 6.2 outlines the way in which Model 1 can account for the first set of three experiments using the 3-year-old design as an example, with 3 objects and Teddy. The Teddy as Character condition is illustrated throughout this discussion since the hypothesis is that subjects in this condition use the Current State Buffer, and the placement of the Current State Buffer within the memory system is the point of discussion in this chapter. In the figure, *123* symbolises the representation of the location of the objects (even when they are probed in the order *321* as in Experiment 3)[34]. Similarly, *T* denotes the representation of Teddy's location as it moves through the system.

It is important to pay special attention to the order in which Teddy and the objects are both tidied and probed relative to one another. In this set of experiments the order can be denoted as *T123 123T;* in other words, Teddy goes to sleep first followed by the hiding of the three objects, and the objects are then probed first followed by Teddy. It is precisely because both the probing and tidying are in this order in Experiments 1 to 3 that Model 1 does not give rise to any interference at input or at output. In Figure 6.2, the representation of Teddy's location is shown entering the Environmental Buffer in box 1, proceeding through the Interpreter Buffer in box 2, and ending up in the Current State Buffer in box 3. In box 4, the tidying of the objects is depicted as they enter the Environmental Buffer. In box 5 the objects enter into the Interpreter Buffer and remain there, as they do not have special status. In box 6 the objects can be seen being output from the Interpreter Buffer. Box 7 then shows Teddy's location being retrieved from the Current State Buffer into the Interpreter Buffer, and finally output from the Interpreter Buffer in box 8. Note here that there is no interference between the location of Teddy and the location of the objects because *T* is already in the Current State Buffer when the objects are hidden. Similarly, when *T* passes through the Interpreter Buffer, the objects have already been output. With different orders of input and output however, the model does predict interference. This approach will be taken shortly after having examined Model 2.

6.3.2 Model 2

The account for Model 2 is displayed in Figure 6.3, and is similar to Model 1 in that it does not produce interference at input or at output with this order of tidying and probing the objects and Teddy. In box 1 of Figure 6.3, *T* reaches the Environmental Buffer and flows straight into the Current State Buffer in box 2 (as opposed to going to the Current State Buffer via the Interpreter Buffer as in Model 1). Box 3 then shows the objects entering the Environmental Buffer, and box 4 shows how they proceed into the Interpreter Buffer before being retrieved in box 5. The start of the retrieval of *T* is pictured in box 6 as it passes through the Interpreter Buffer, culminating in its exit out of the system in box 7. Again, with this order there has been no interference between the representations of Teddy's and the objects' locations.

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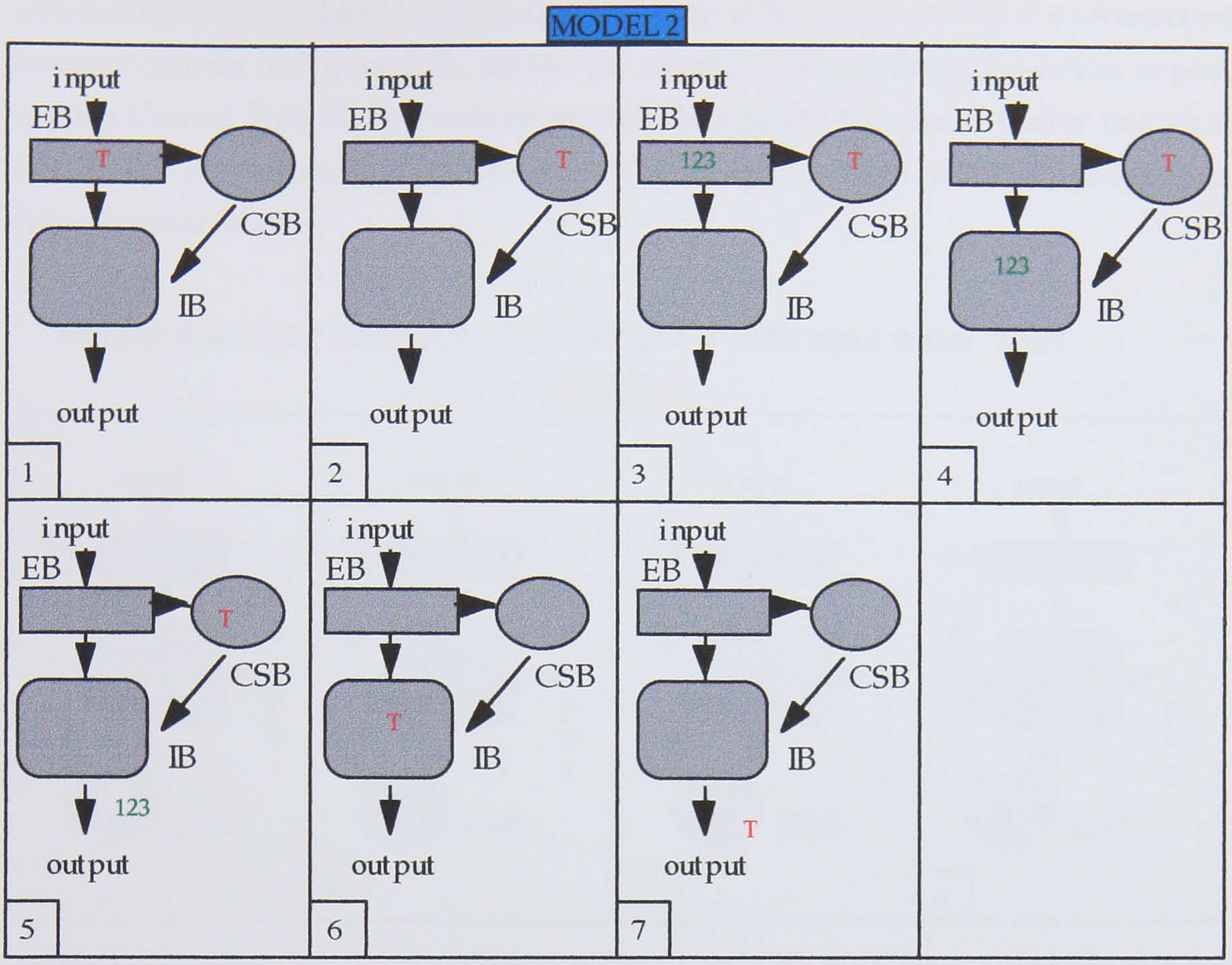
[34] The simplifying assumption made here is that the object locations are stored together as one unit.

Figure 6.3 How Model 2 explains Experiments 1, 2 and 3 *(T123 123T)*



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, and "CSB" is Current State Buffer.

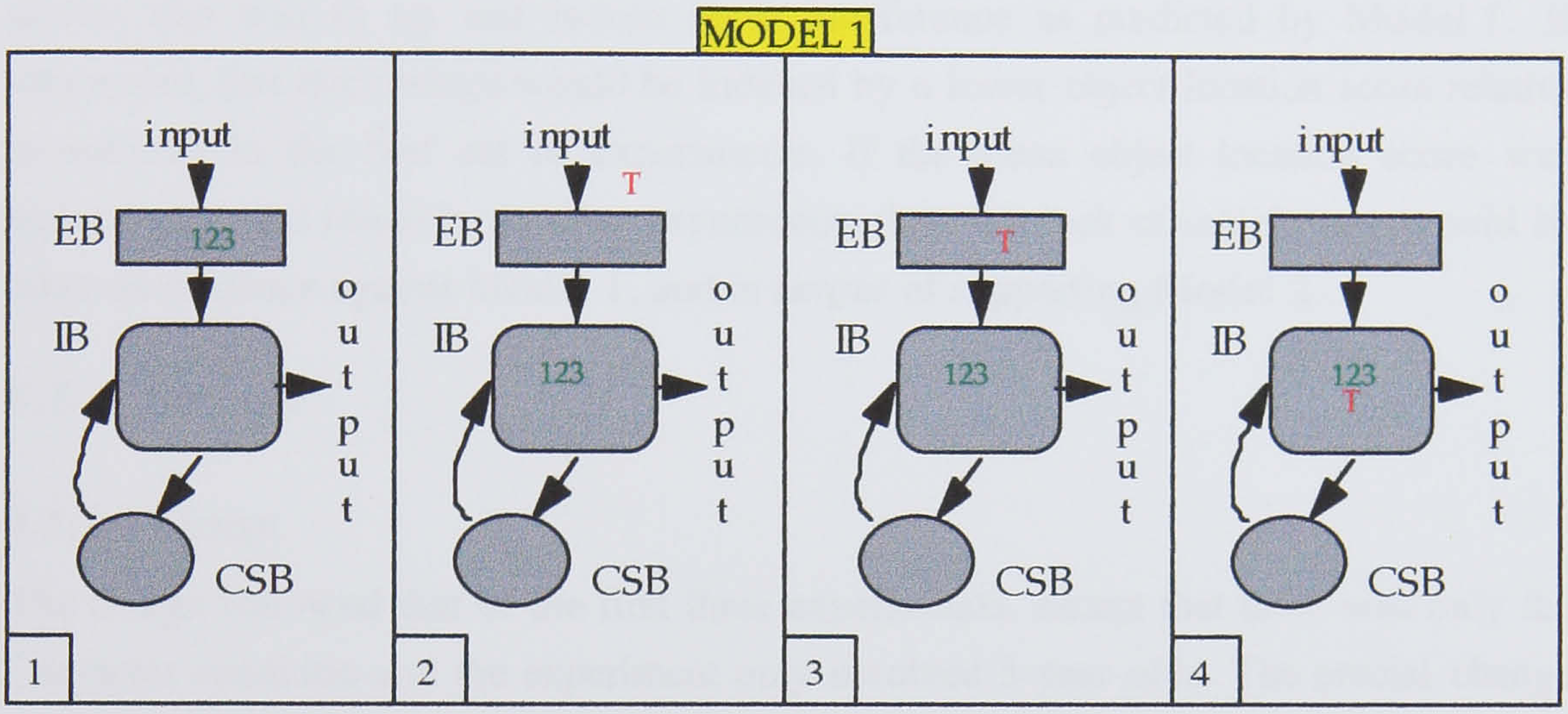
6.4 Deciding Between Model 1 and Model 2

If both Models 1 and 2 can readily account for the existing data set, then there must be a way of empirically deciding between these two options. The Tidy Emu Paradigm lends itself to achieving this, if the orders of the tidying and the probing of the objects and Teddy in the Character condition are varied. I shall now examine what these two models predict, when the input and output orders are varied.

6.4.1 Varying Input Order

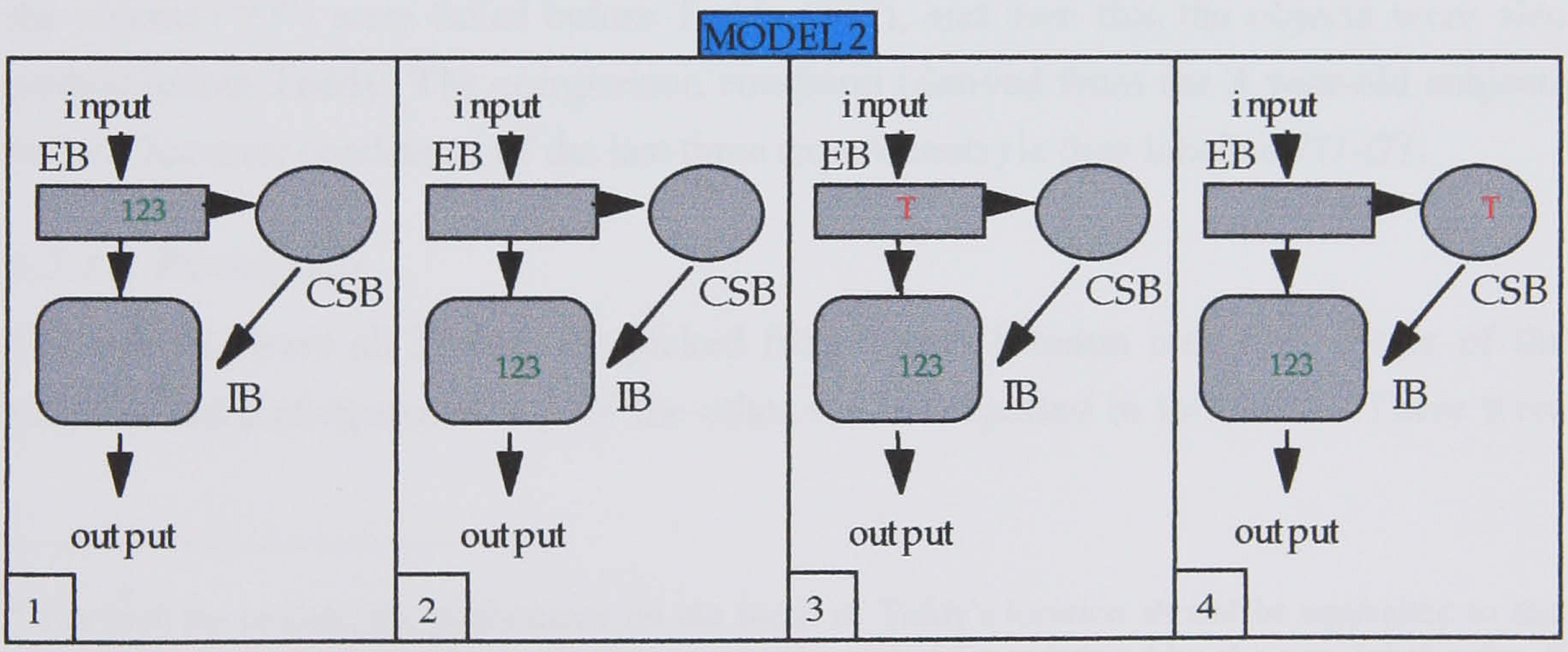
Suppose the input order is changed from *T123* (as was featured in the first three experiments) to *123T*. With this design, the objects are tidied away prior to Teddy going to sleep, and the two models have differential predictions about whether there will be any interference at input. As sketched in Figure 6.4, Model 1 predicts input interference when Teddy goes to sleep. The reason for the interference is that when Teddy goes to sleep, the new location of Teddy is registered (boxes 3 and 4), and the representation of his location has to pass through the Interpreter Buffer, where the representation of the location of the objects is stored (box 4). This disrupts the representation of the object locations that are being stored there. Model 2's architecture however (shown in Figure 6.5), allows the representation of Teddy's location to pass into the Current State Buffer without passing through the Interpreter Buffer (boxes 3 and 4), and thus preventing interference with the representation of the object locations that are stored there.

Figure 6.4 Input interference for Model 1 with input order *123T*



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, and "CSB" is Current State Buffer.

Figure 6.5 No input interference for Model 2 with input order *123T*



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, and "CSB" is Current State Buffer.

Hence with this new input order of *123T*, and with the original output order of *123T*, Experiment 4 is a way of implicating one of the models as the better account of the data. If the performance of subjects in the Character condition on object locations is equal to the performance of subjects in the Character conditions in the first set of experiments, where the order was *T123 123T,* then this lack of interference will implicate Model 2. If however, the object performance is lower than that of the first set of experiments, then this will implicate Model 1.[35]

6.5 Experiment 4

Experiment 4 just used 3-year-old "Character" subjects, and varied the order of events in the existing Tidy Emu Paradigm from *T123 123T* to *123T 123T.* As explained above, this was to try and induce input interference as predicted by Model 1. If successful, this interference would be indexed by a lower object location score relative to subjects in the first set of experiments. If the mean object location score was equivalent to that found in the first experiments then this lack of interference would be taken as evidence against Model 1, and in favour of supporting Model 2.

6.5.1 Method

6.5.1.1 Design

The design followed that of the first three experiments, except that there was only the Character condition and the experiment only involved 3-year-olds. The crucial change to the design was the change in input order of the stimuli to hiding the objects before Teddy. This condition was compared with the Character conditions of the 3-year-olds in the first three experiments (where the input order had Teddy sleeping before the object pairings). Thus the condition in this experiment is termed *OT-OT,* to denote that the objects ("O") were tidied before Teddy ("T"), and then that the objects were also probed before Teddy. The comparison condition (derived from the 3-year-old subjects in the Character conditions of the last three experiments) is thus labelled *TO-OT.*

6.5.1.2 Participants

The subjects were all 3-year-olds picked from North London nurseries. None of the subjects had participated in any of the other studies reported in this thesis. There were

[35] For both the models, the performance on the recall of Teddy's location should be equivalent to that found in the first set of experiments if there is no object interference induced by the new input order. If there is input interference, however, one prediction may be that because the Current State Buffer is still below capacity in having to track just one character, this is unlikely to initiate much of a drop in performance. This is the simple assumption made here. However, it should be noted that the matter may be more complex, because the representation of the object locations may benefit from active preservation by Working Memory, since the subjects are instructed to remember the locations. The representation of Teddy's location, on the other hand, has been tracked without instruction. The result of object interference may lead to a more complex trade-off between the incidental notion of Teddy's location and the preservation of the object locations, resulting in a possible decrease in the recall of Teddy's location.

14 subjects (2 in each of the 7 randomisations), and the mean age was 3;8 (range, 3;2 to 3;12).

6.5.1.3 Apparatus

The apparatus was identical to that used in the Character conditions of Experiments 1, 2 and 3.

6.5.1.4 Procedure

Note that there was no Object condition in the experiment, and thus the procedure just relates to a Character condition.

The procedure was identical to that used in the Character condition of Experiment 3 with two major exceptions. First, instead of Teddy going to sleep just before Emu tidies away his toys, Teddy stays out on the table as the toys are tidied away into the receptacles, and only then goes to sleep. Thus after they have interacted with him, the subjects are told that Teddy is tired, but Teddy is just left sitting on the table until after the toys have been tidied away. The subjects are given the identical "story" to that given in the Character condition of the previous experiments when Emu arrives and tidies the toys. Immediately after this, they are told that Teddy is going to go to sleep, and he is seen to walk to one of the receptacles as in the previous studies.

The second difference with respect to Experiment 3 is that although the probing order is the same for the purposes of this study, with Teddy's location probed after the objects, the objects are probed in the order they were tidied *(123)* as in Experiments 1 and 2, and not in the reverse order *(321)* as in Experiment 3.

6.5.2 Results

The total number of correctly recalled object locations (out of three) for each subject was noted. The mean number of correctly recalled locations from this condition (OT-OT) was compared with that of the 3-year-old subjects in the Character conditions of the first three experiments (TO-OT). This is tabulated below in Table 6.1, together with the standard deviations and sample sizes for the two conditions.

An independent samples t-test was carried out to test for a difference between the two means, which failed to show a significant difference between the two means ($t = 0.38$, $df = 54$, n.s. $p > 0.05$).

TABLE 6.1 MEAN RECALL OF OBJECT LOCATIONS IN EXPERIMENT 4

Experiment/Condition	Tidy and Probe order	Mean/ 3	S.D.	n
Experiment 4 OT-OT	*123T 123T*	**2.07**	**0.92**	**14**
Experiments 1-3 TO-OT	*T123 123T*	**1.95**	**1.03**	**42**

Data from Experiment 4 (OT-OT) is compared with the mean performance on object locations from the Character conditions of Experiments 1-3 (TO-OT).

All the children remembered the location of Teddy.

6.5.3 Discussion

The fact that the mean correct object score was equivalent to the performance recorded in the first set of experiments, with the change of input order, indicates that there was no input interference. Therefore this provides evidence against Model 1, and in favour of Model 2 as an appropriate architecture for the system. Now that Model 2 has been implicated, it is important to gain further evidence in favour of Model 2 by testing the predictions that it makes about output interference.

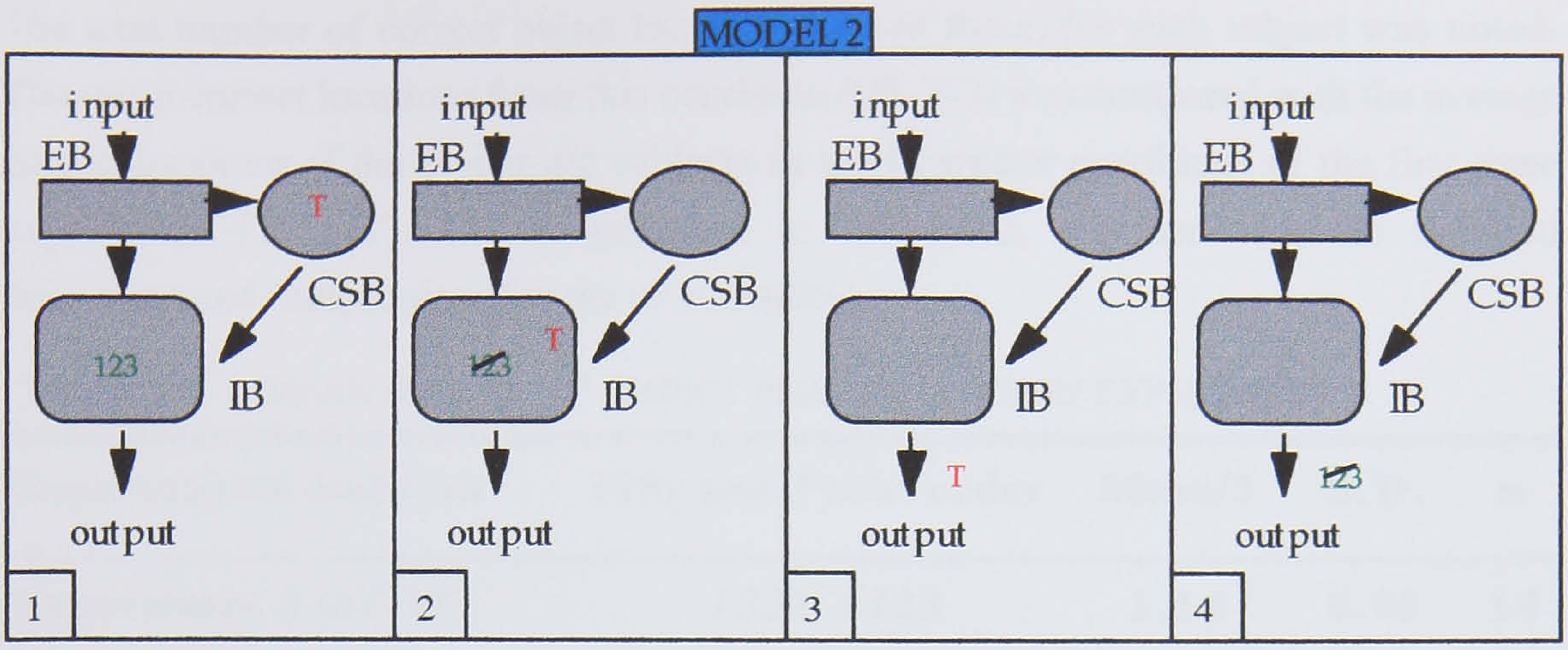
6.6 Gaining Further Support For Model 2

6.6.1 Varying Output Order

If the order of *probing* is now changed from that featured in the past set of experiments to *T123*, that is, asking for Teddy's location before asking for the location of the objects, Model 2 has explicit predictions. As shown in Figure 6.6, assuming that "T" and "123" are safely stored in the Current State Buffer and the Interpreter Buffer respectively (box 1), if Teddy 's location is retrieved first then this will lead to interference on object location performance (box 2) when the object locations are retrieved (box 4).

Thus Experiment 5 is a way of gaining further support for the viability of Model 2. The firm prediction from Model 2 is that as a result of changing the output order of *123T* in Experiment 4, to *T123* in Experiment 5, there will be a drop in the mean correct object locations recalled by the subjects.

Figure 6.6 Output interference for Model 2 when output order is *T123*



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, and "CSB" is Current State Buffer.

6.7 Experiment 5

Experiment 5 was identical in every respect to Experiment 4, except that the order of probing was *T123*, instead of *123T*.

6.7.1 Method

6.7.1.1 Design

The design was identical to Experiment 4, and the data from the new condition *(123T T123)* was also compared with the data from the first three studies. The new condition was termed *OT-TO*, and the comparison condition is still termed TO-OT.

6.7.1.2 Participants

The participants were 3-year-olds picked at random from nurseries in North London. None of the subjects had participated in any of the other studies reported in this thesis. There were 14 subjects (2 in each of the 7 randomisations), and the mean age was 3;5 (range, 3;3 to 3;11).

6.7.1.3 Apparatus

The apparatus in Experiment 5 was identical to that used in Experiment 4.

6.7.1.4 Procedure

The procedure was identical to that employed in Experiment 4, except that instead of probing for Teddy's location after the objects, Teddy's location was probed first, before the objects.

6.7.2 Results

The total number of correct object locations (out of three) for each subject was noted. The mean correct locations from this condition (OT-TO) was compared with the average correct locations of the 3-year-old subjects in the Character conditions of the first three experiments (TO-OT). This is tabulated in Table 6.2, together with the standard deviations and sample sizes for the two conditions.

TABLE 6.2 MEAN RECALL OF OBJECT PERFORMANCE IN EXPERIMENT 5

Experiment/Condition	Tidy and Probe order	Mean/3	S.D.	n
Experiment 5 OT-TO	*123T T123*	**1.14**	**0.95**	**14**
Experiments 1-3 TO-OT	*T123 123T*	**1.95**	**1.03**	**42**

Data from Experiment 5 (OT-TO) is compared here with the mean performance on object locations from the Character conditions of Experiments 1-3 (TO-OT).

An independent samples t-test was computed to test for a difference between the two means, revealing that there was a significant difference ($t = 2.58$, $df = 54$, sig. $p < 0.013$).

All the subjects recalled Teddy's location perfectly.

6.7.3 Discussion

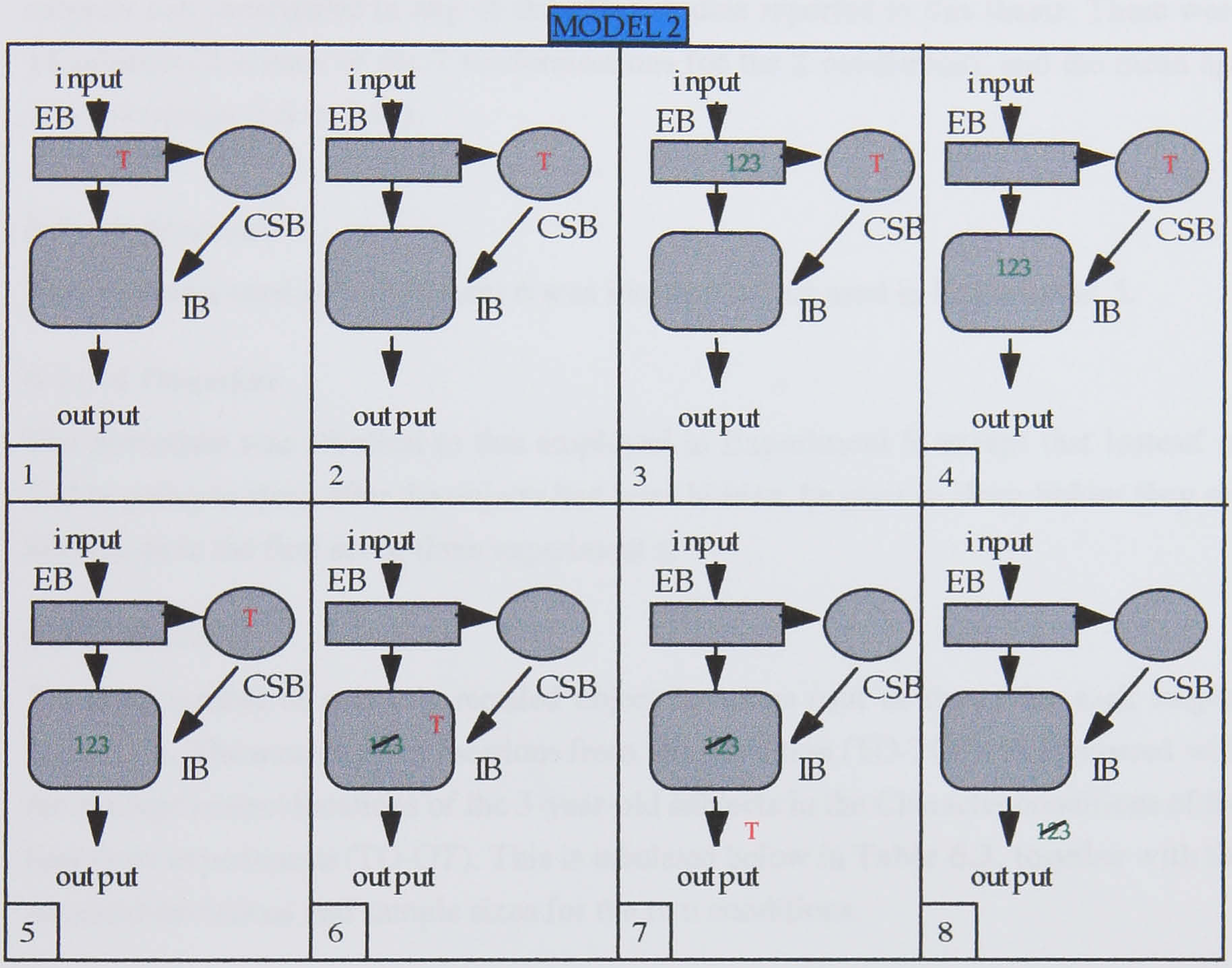
The results suggest that there is output interference since the mean correct object location performance had dropped to 1.14. This was explicitly predicted by Model 2 and thus gives further support to Model 2 as an appropriate version of the system architecture. However, before Model 2 can be fully accepted, one further combination of input and output order needs consideration. The predictions derived from Model 2 regarding the performance of subjects on this hitherto untested order of tidying and probing will be articulated and then checked through its implementation in Experiment 6.

6.8 The Final Test of Model 2

Model 2 predicts output interference when the output order is *T123*, regardless of input order. Thus far, Model 2 has certainly been implicated since there was interference in Experiment 5 with the tidy and probe order: *123T T123*. It follows therefore that if the tidy and probe order is *T123 T123*, even though the input order has reverted back to the original order in the first three experiments, there should still be output interference.

Figure 6.7 demonstrates this pictorially. Shown in boxes 1 to 4 is that Model 2 does not predict input interference. However, in boxes 5 to 8 it can be seen that output interference is still predicted.

Figure 6.7 Output interference is still predicted by Model 2 when tidy and probe order are: *T123 T123*



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, and "CSB" is Current State Buffer.

6.9 Experiment 6

Experiment 6 therefore runs this final test of Model 2, with the order of events - *T123 T123*. As mentioned above, the prediction from Model 2 is that the mean correct object location performance will still suffer from output interference, with a score equivalent to the OT-TO condition in Experiment 5.

6.9.1 Method

6.9.1.1 Design

This was identical to the design of Experiment 5, except that tidying order was changed to the original sequence of the first set of experiments whereby Teddy goes to sleep before his toys are tidied away. This condition was labelled TO-TO, and was compared with the TO-OT condition.

6.9.1.2 Participants

The participants were 3-year-olds picked at random from North London. None of the subjects had participated in any of the other studies reported in this thesis. There were 14 subjects (2 in each of the 7 randomisations for the 2 conditions), and the mean age was 3;4 (range, 3;0 to 3;11).

6.9.1.3 Apparatus

The apparatus used in Experiment 6 was identical to that used in Experiment 5.

6.9.1.4 Procedure

The procedure was identical to that employed in Experiment 5, except that instead of Teddy going to sleep after the objects had been hidden, he goes to sleep before they are hidden, as in the first set of three experiment s.

6.9.2 Results

The total number of correctly recalled object locations (out of three) for each subject was noted. The mean correct locations from this condition (TO-TO) was compared with the average correct locations of the 3-year-old subjects in the Character conditions of the first three experiments (TO-OT). This is tabulated below in Table 6.3, together with the standard deviations and sample sizes for the two conditions.

TABLE 6.3 MEAN RECALL OF OBJECT LOCATIONS IN EXPERIMENT 6 COMPARED WITH THE CHARACTER CONDITIONS OF EXPERIMENTS 1-3

Experiment/Condition	Tidy and Probe order	Mean/3	S.D.	n
Experiment 6 TO-TO	*T123 T123*	**1.86**	**1.01**	**14**
Experiments 1-3 TO-OT	*T123 123T*	**1.95**	**1.03**	**42**

Data from Experiment 6 (TO-TO) is compared here with the mean performance on object locations from the Character conditions of Experiments 1-3 (TO-OT)

An independent samples t-test was carried out to test for a difference between the two means, failing to show any significant difference ($t = 0.29$, $df = 54$, n.s. $p > 0.05$).

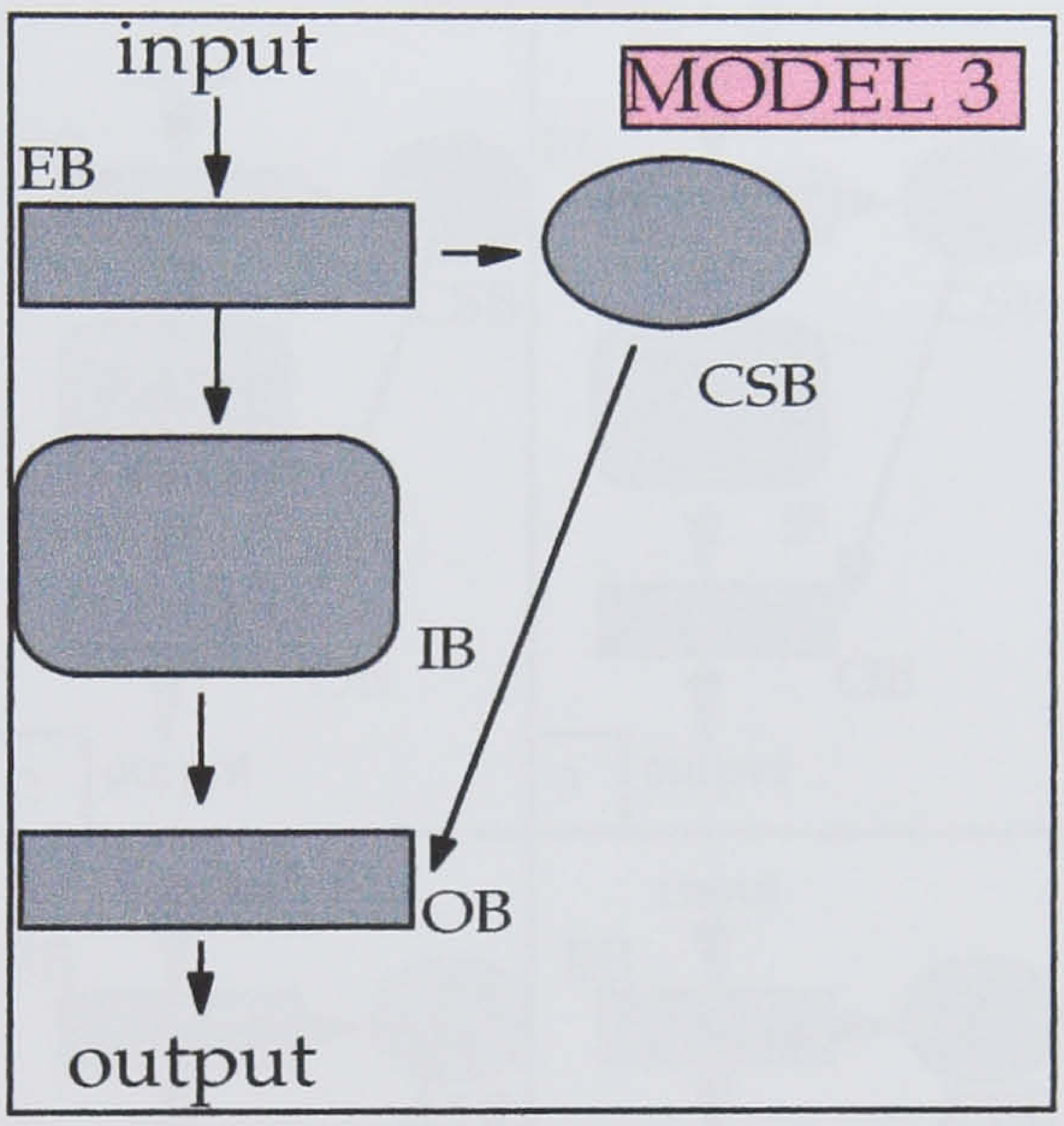
All the subjects recalled Teddy's location correctly.

6.9.3 Discussion

The results suggest that there was no input interference since the mean correct object location performance had not decreased as Model 2 had predicted. Thus even though Experiment 4 had ruled out Model 1, and implicated Model 2 - which was then granted further support from its accurate prediction in Experiment 5 - Experiment 6 has demonstrated that Model 2 cannot give an accurate account of the data. A slightly more complex model, based on Model 2, is therefore necessary. This is *Model 3*, and I will now describe how it can accommodate the existing data set. During the course of this explanation, a prediction based on Model 3 will be made and Experiment 7 will be carried out to test this.

6.10 Model 3

Figure 6.8 Model 3



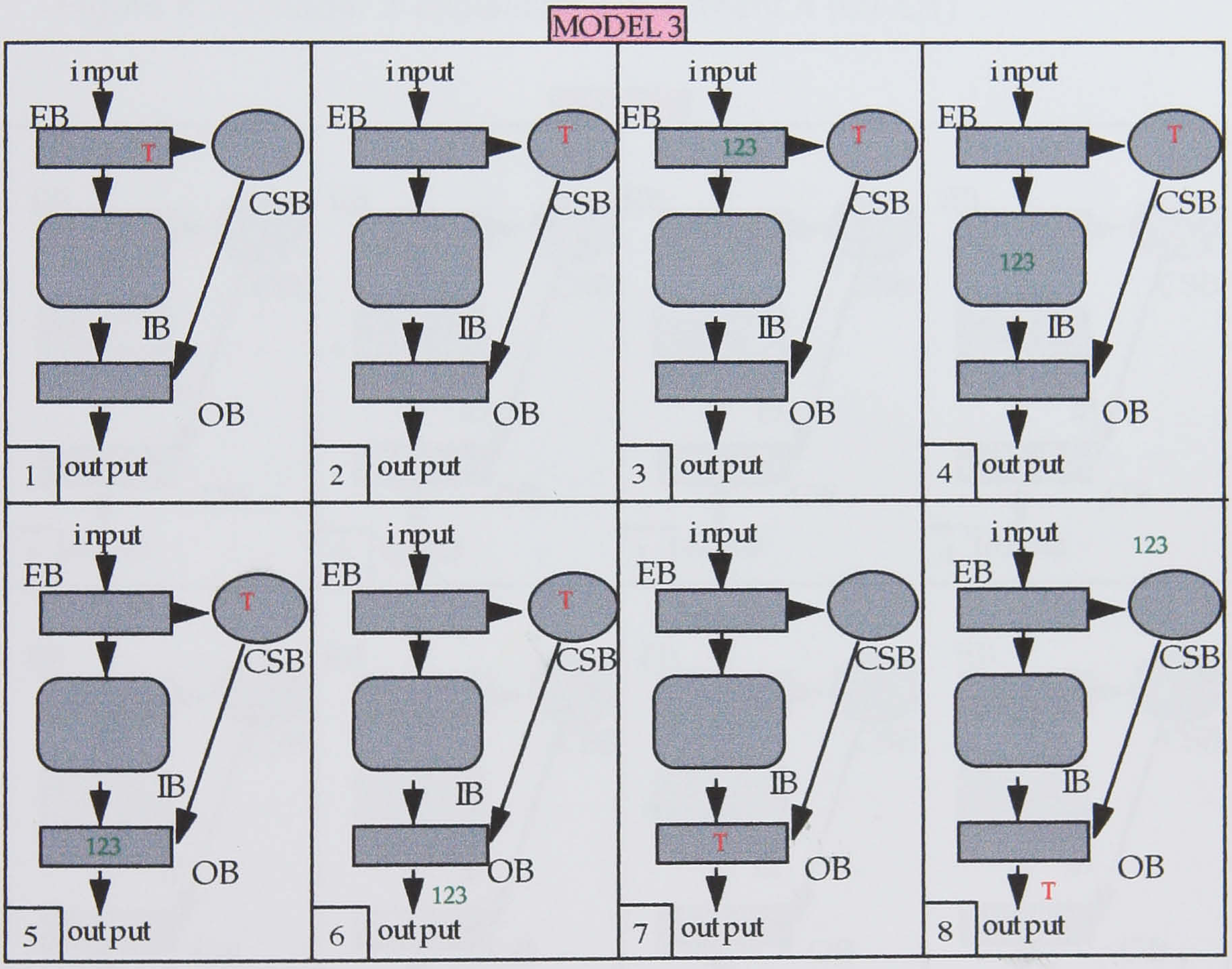
"EB" is Environmental Buffer, "IB" is Interpreter Buffer, "CSB" is Current State Buffer and "OB" is Output Buffer.

Model 3 is pictured in Figure 6.8 and its structure is based on the overall architecture of Model 2, with the Current State Buffer receiving input from the Environmental Buffer. The data indicate that Teddy can be output without interference. The simplest change is to allow output from the Current State Buffer, bypassing the Interpreter Buffer. An Output Buffer in any case can allow for speeded output. This effectively will prevent the type of output interference predicted by Model 2. Similarly, because the position of the Current State Buffer in Model 3 is identical to its placement in Model 2, the input interference predicted by Model 1 is also avoided. Hence if all of this interference is avoided in Model 3, the one remaining finding to explain is that of the decreased object performance in the OT-TO condition (Experiment 5, see section 6.7), and this will be considered shortly.

It will be noticed that there is a path from the Current State Buffer direct to the Output Buffer. Originally the assumption was made that at retrieval information flowed from the Current State Buffer and into the Interpreter Buffer. This was based on an experiment by Barreau (1997) in which she intentionally overloaded all the Buffers of her subjects. However in the current set of experiments the Current State Buffer is not at capacity, and so this assumption may not have to be made.

6.10.1 How Model 3 can Explain the Existing Data Set

Figure 6.9 Model 3 explaining Experiments 1-3 (TO-OT)



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, "CSB" is Current State Buffer and "OB" is Output Buffer.

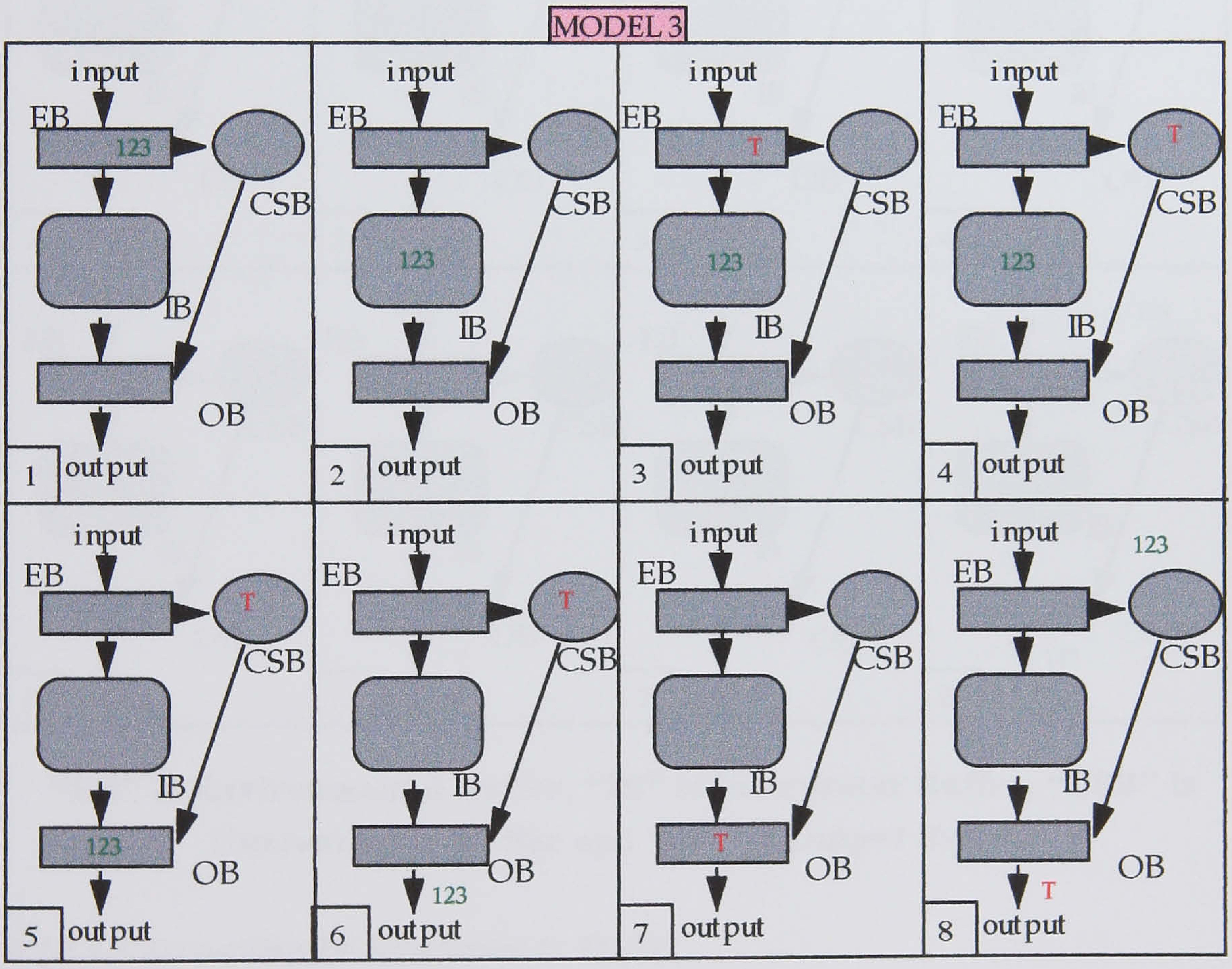
As I have noted, within Model 3, there is now no necessity for input or output interference with the current design, whatever the tidying or probing order. The main question therefore is why there is a decrease in mean correct object performance in

Experiment 5, and I shall explain this after I have described how the data from the other conditions can be readily explained by Model 3.

6.10.1.1 Accounting for Experiments 1-3: TO-OT

Figure 6.9 describes the information flow in Model 3 during Experiments 1, 2 and 3. At input, Teddy's location flows via the Environmental Buffer into the Current State Buffer (boxes 1 to 2), and the representation of the object locations enters into the Interpreter Buffer, via the Environmental Buffer (boxes 3 to 4). At output, the representation of the object locations flow straight out of the Interpreter Buffer into the Output Buffer and out of the system (boxes 5 to 6), and Teddy's representation then proceeds straight into the Output Buffer from the Current State Buffer (box 7), and out of the system (box 8).

Figure 6.10 Model 3 explaining Experiment 4 (OT-OT)

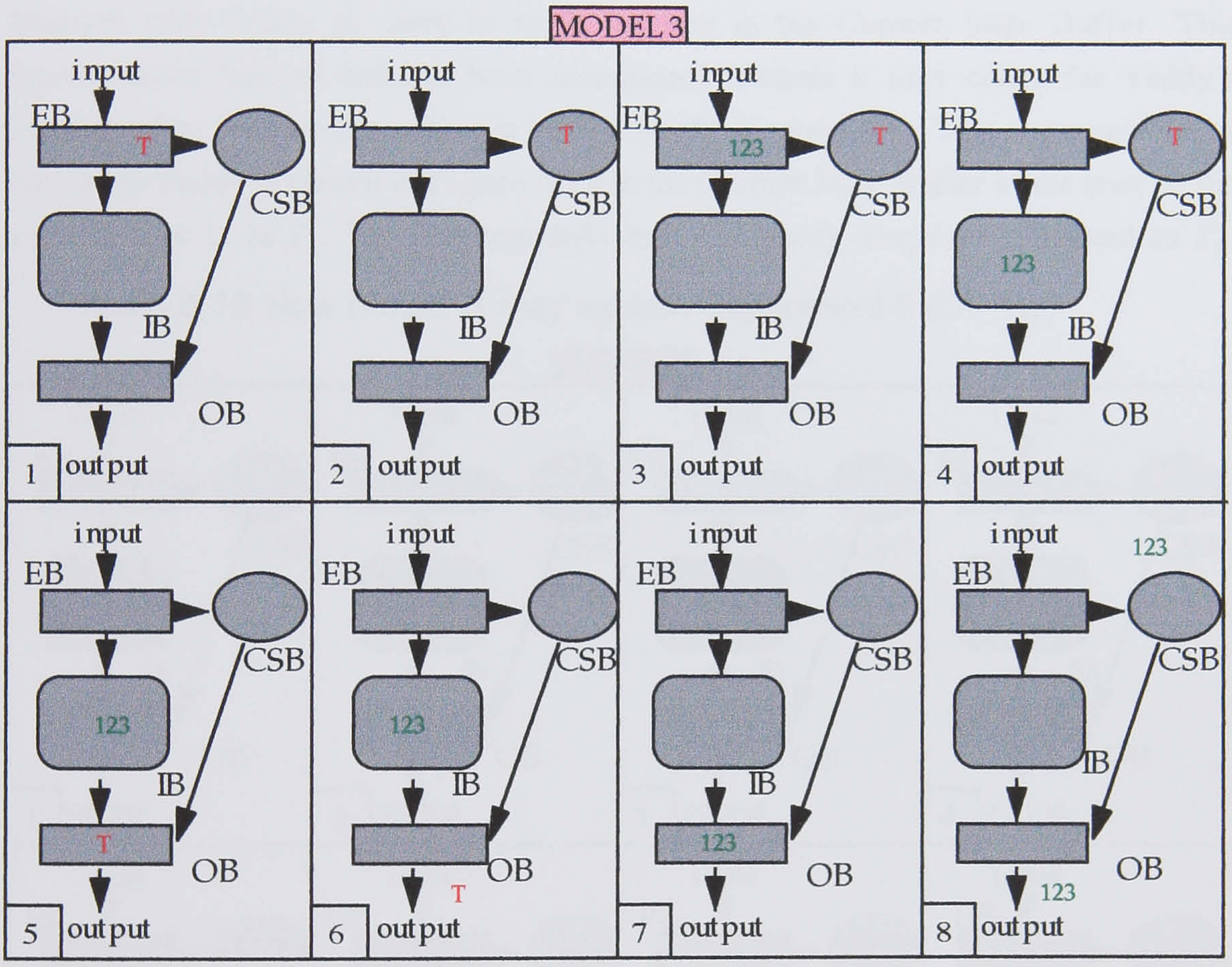


"EB" is Environmental Buffer, "IB" is Interpreter Buffer, "CSB" is Current State Buffer and "OB" is Output Buffer.

6.10.1.2 Accounting for Experiment 4: OT-OT

Figure 6.10 (above) displays how information flows through Model 3 in Experiment 4. In boxes 1 to 2, the representation of the object locations enter the Environmental Buffer and pass into the Interpreter Buffer. In boxes 3 to 4, the representation of Teddy's location enters the Environmental Buffer and flows into the Current State Buffer. Boxes 5 to 6 show the safe exit of the representations of the object location from the system, and boxes 7 to 8 display the representation of Teddy leaving the system.

Figure 6.11 Model 3 explaining Experiment 6 (TO-TO)



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, "CSB" is Current State Buffer and "OB" is Output Buffer.

6.10.1.3 Accounting for Experiment 6: TO-TO

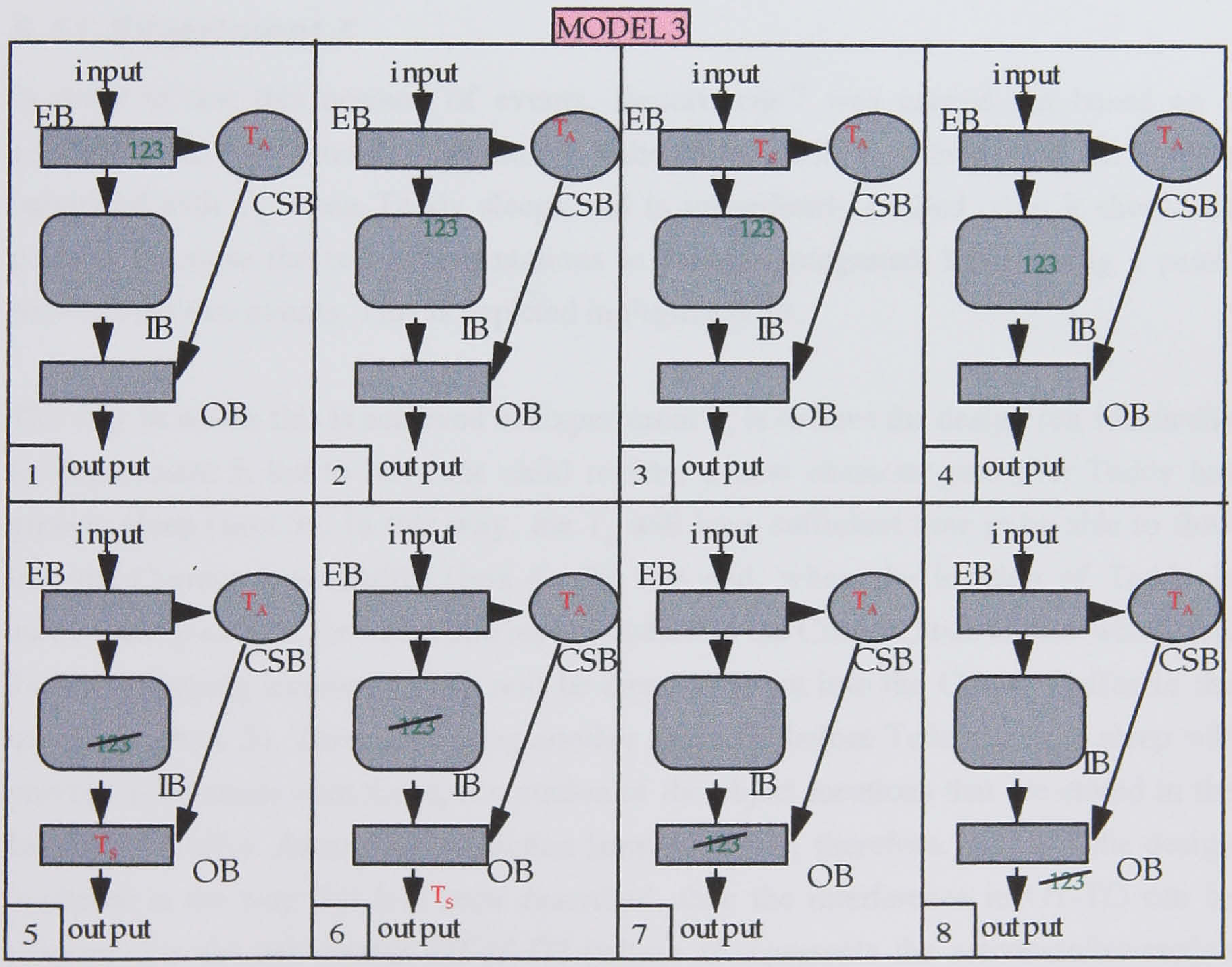
Figure 6.11 (above) displays how Model 3 can account for the entry and exit of the representations of the stimuli locations in Experiment 6. In boxes 1 to 2 the input of Teddy's representation is shown entering the system via the Environmental Buffer and flowing into the Current State Buffer. Boxes 3 to 4 show the entry of object location representations. The retrieval of the representation of Teddy is then displayed in boxes 5 to 6, and then the retrieval of the object locations is shown in boxes 7 to 8.

6.10.1.2 Accounting for Experiment 5: OT-TO

The first thing to note about the tidying and probing order in this condition is that Teddy's location changes when he goes to sleep, and the subject is immediately asked for his location. The reason for the drop in correct object location performance in this condition may have something to do with the amount of time between Teddy being tracked as going to sleep in a receptacle, and being probed for his location. Let me explore this further.

Thus far, what I have not thought about is the process by which a Current State Buffer entry is actually made. In all Character conditions, I assumed that when the subject interacts with Teddy an entry is made for him in the Current State Buffer. This representation has not hitherto been mentioned, because it only codes for Teddy's location when he is awake, which is not in one of the receptacles. This representation of the *awake* Teddy is shown in Figure 6.12 in the Current State Buffer at the start of the event in box 1, as T_A. The (unintegrated) entry for Teddy *sleeping* is denoted as T_S.

Figure 6.12 How Model 3 may explain Experiment 5 (OT-TO)



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, "CSB" is Current State Buffer and "OB" is Output Buffer. "T_A" denotes the representation of Teddy when he is awake, and "T_S" when he is asleep.

Other entries in the Current State Buffer would include the experimenter and Emu, when he appears. When Teddy goes to sleep after the objects have been tidied, and changes locations, the new location of Teddy enters the Environmental Buffer (in box 3). Normally, this representation would pass into the Current State Buffer, becoming integrated with the existing representation of Teddy, and updating his status in this way. For simplification purposes, the "representation of Teddy's location" when he is asleep has up until now, actually been referring to this integrated representation of Teddy's new location, registered in the Current State Buffer.

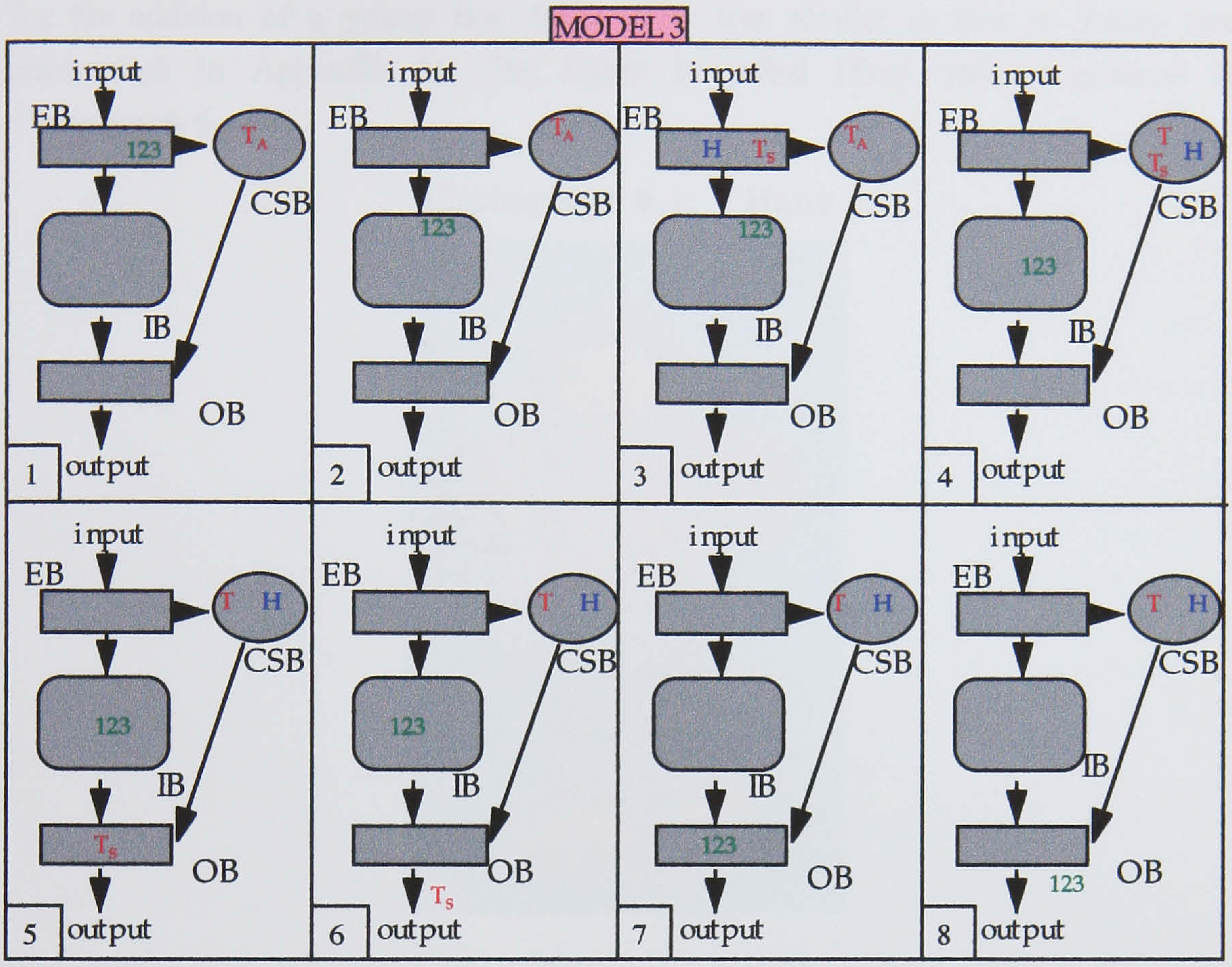
However, if there is not sufficient time for this integration between the existing representation of Teddy in the Current State Buffer and his new sleeping location, as in Experiment 5, then if Teddy's sleeping location is probed it will be output straight from the Environmental Buffer (box 4), and out through the Interpreter Buffer (without ever entering the Current State Buffer), leading to interference with the objects that are stored there (box 5). In Experiment 5 this may have been what happened, due to the brief amount of time between Teddy sleeping and his location being probed.

6.11 Experiment 7

In order to test this account of events, Experiment 7 was carried out based on a prediction derived from this explanation. If there was insufficient time for T_S to become integrated with T_A when Teddy sleeps and is immediately probed, then it should be possible to cause the two representations to become integrated, by inserting a pause between the two events. This is depicted in Figure 6.13.

The way in which this is achieved in Experiment 7, is to have the design run identically to Experiment 5, but to have the child register a new character just after Teddy has gone to sleep (box 3). In this way, the T_S will have sufficient time to be able to flow into the Current State Buffer (box 4). To this end, when the location of Teddy is subsequently output, the integrated representation in the Current State Buffer which has Teddy's sleeping location coded, will be directly output into the Output Buffer in the usual way (box 5). Thus, activating another character before Teddy goes to sleep will prevent interference with the representation of the object locations that are stored in the Interpreter Buffer. An explicit prediction from Model 3, therefore, is that if the design is altered in the way that has been described, then the interference in OT-TO can be eliminated in the new design *OT-H-TO* (where *H* represents the activation/interaction with an additional character).

Figure 6.13 How Experiment 7 prevents interference from T_S



"EB" is Environmental Buffer, "IB" is Interpreter Buffer, "CSB" is Current State Buffer and "OB" is Output Buffer. T_A denotes the representation of Teddy's location when he is awake, and T_S when he is asleep.

6.11.1 Method

6.11.1.1 Design

This was identical to the design of Experiment 6, except that after Teddy had gone to sleep, there was a short interaction with another character, Hans, who was not hidden in the receptacle set. This condition was labelled *OT-H-TO* (where *H* stands for the interaction with Hans) and was compared with the *TO-OT* condition.

6.11.1.2 Participants

The participants were 3-year-olds picked at random from nurseries in North London. None of the subjects had participated in any of the other studies reported in this thesis. There were 14 subjects (2 in each of the 7 randomisations), and the mean age was 3;8 (range, 3;6 to 3;10).

6.11.1.3 Apparatus

The apparatus used in Experiment 6 was identical to that used in Experiment 6, except for the addition of a young boy figure who was similar in size to Teddy (see photograph in Appendix 4). The figure is called Hans and is pictured in Photograph 6.1.

Photograph 6.1: Hans

6.11.1.4 Procedure

The procedure was identical to that employed in Experiment 5, except that just after Teddy has gone to sleep and before probing begins, the subject is introduced to Hans. The subject shakes hands with Hans and he says "pleased to meet you", mentioning the name of the subject. Hans then goes to sit to the side of the table for the duration of the trial. Immediately following this interaction, Probing begins with Teddy's location followed by that of the objects.

6.11.2 Results

The total number of correct object locations (out of three) for each subject was noted. The mean correct locations from this condition (OT-H-TO) was compared with the average correct locations of the 3-year-old subjects in the Character conditions of all the other experiments. This is tabulated below in Table 6.4, together with the standard deviations and sample sizes for the conditions.

An independent samples t-test was carried out to test for a difference between the means of the first three experiments (TO-OT) and that of Experiment 7, which showed no significant difference ($t = 0.30$, $df = 54$, n.s. $p > 0.05$).

TABLE 6.4 MEAN RECALL OF OBJECT PERFORMANCE IN EXPERIMENT 7

Experiment/Condition	Tidy and Probe order	Mean/3	S.D.	n
Experiment 7 OT-H-TO	*T123 H T123*	**1.86**	**1.03**	**14**
Experiment 6 TO-TO	*T123 T123*	**1.86**	**1.01**	**14**
Experiment 4 OT-OT	*123T 123T*	**2.07**	**0.92**	**14**
Experiments 1-3 TO-OT	*T123 123T*	**1.95**	**1.03**	**42**
Experiment 5 OT-TO	*123T T123*	**1.14**	**0.95**	**14**

The means from Experiment 7 (OT H TO) are compared with the means from the subjects in the Character conditions in Experiments 1- 6.

A between subjects ANOVA was then performed in order to compare the correct mean object performance in Experiment 5 with that of the other studies. A significant difference was found with $F(1,93) = 7.03$ sig $p < 0.0094$, suggesting that the difference between 1.14 compared with the other scores, are due to interference.

6.11.3 Discussion

As predicted by Model 3, the activation of Hans lead to the integration of the representation of Teddy's sleeping location and his entry in the Current State Buffer, allowing output via the Current State Buffer and not through the Interpreter Buffer, which would have lead to interference (as in OT-TO).

6.12 Summary

This chapter began by examining two possible architectures that can accommodate the data in the first three experiments (section 6.3).Experiments 4 and 5 were performed and one of these models was implicated. However, an additional study (Experiment 6) indicated that a different model to this was necessary to accommodate all the findings. A third model was derived and specified, and a more complex explanation of the information processing in the Tidy Emu Paradigm was considered. This explanation lead to a prediction, which was then tested and confirmed in Experiment 7.

CHAPTER 7

Multiple Characters

7.1 Chapter Outline

In the last chapter, I investigated the architecture of a system with a Current State Buffer. This chapter now goes on to explore the nature of the Current State Buffer and its interactions with Working Memory. Two studies are reported in the chapter, Experiments 8 and 9, both of which use the basic Tidy Emu paradigm. Instead of just Teddy interacting with the subjects in the Character condition, Experiment 8 introduces an additional character, Hans, who interacts with the child as well as Teddy. In Experiment 9 one further character, Bunny, joins Teddy and Hans in interacting with the child.

Hence these two studies extend the first set of experiments, which all used one character, by systematically increasing the number of characters that the Current State Buffer must track. It is suggested that this increase in character load on the Tidy Emu Paradigm is an effective approach for investigating the nature of the Current State Buffer. It is then argued that the interactions between the Current State Buffer and Working Memory are a function of age and of the number of characters that are to be tracked by the Current State Buffer.

7.1.1 The Effects of Increasing the Character Load

The focus of this thesis is to examine the Current State Buffer. As mentioned in earlier chapters, this is a novel construct which, to date, has not been established as independent. Similarly, the nature of the Current State Buffer has not been investigated. Hence it is difficult, if not almost impossible, to have one set of solid predictions about the nature of the Current State Buffer and its interactions with Working Memory. What follows therefore is a consideration of what may be revealed when the character load is increased.

First, the effect of introducing extra characters is important in assessing the capacity of the Current State Buffer. In the first set of experiments, for example, the subjects in the Character conditions used their Current State Buffers to track Teddy. It will be recalled that their performance on this task was at ceiling level, since all the subjects in the condition were able to recall Teddy's location correctly. From this particular result, only one thing can be said about the capacity of the Current State Buffer. This is that subjects in these two age groups are able to track at least one character location perfectly in their

Current State Buffers. It could be the case that they are unable to track more than one character, but the measure of Current State Buffer function that was employed in these experiments was simply not powerful enough to explore this. Clearly, adding extra characters for the subjects in the Character condition to track is a way of measuring the capacity of Current State Buffer performance in this task. Incrementing the character load to two characters in Experiment 8, and to three characters in Experiment 9, may allow a more accurate measure of Current State Buffer function. A simple hypothesis, of course, would be that both age-groups of children are able to track the locations of all of the characters (leading to further ceiling effects on character location performance). Another hypothesis is that they can only track one character location. A more likely hypothesis is that the capacity of the Current State Buffer is age-dependent. In other words, older subjects are able to track more character locations than younger subjects, but as with the younger the subjects, the older subjects cannot track all the character locations.

In establishing the capacity of the Current State Buffer in this way, the increase in the number of character locations that the subjects have to register could mean that for a given number of characters, the Current State Buffer is overloaded to some extent. Note that this is consistent with the notion of a fixed capacity of the Current State Buffer. Will this overloading lead to any deleterious effects on Current State Buffer function, and are any effects age-dependent? A further question may also be answered by increasing the Current State Buffer load. That is, will the effect of increasing the load on the Current State Buffer have any effect on Working Memory performance? If the explicit Working Memory load in the task (three object locations for 3-year-olds, and four object locations for 4-year-olds) is held constant for the two age-groups, then with the increase in character load, any resultant effects on Working Memory can be scrutinised. Resources may be re-allocated from Working Memory to support the function of the Current State Buffer when the demands on the Current State Buffer have been increased through raising the Current State Buffer load. Age-dependent effects may once again emerge due to the differing meta-cognitive abilities of the two age-groups. The idea that the Current State Buffer tracks important stimuli in the environment, could well mean that in certain situations, the Current State Buffer would take precedence over Working Memory, and siphon-off some of its resources.

The methods of Experiments 8 and 9 will now be described consecutively in sections 7.2 and 7.3. Following this, I shall report the results from both sets of experiments together, and compare them with the *one Character* condition which featured in the first three experiments (sections 7.4 to 7.6). In the same way, all of these results will be dealt with as a whole in one discussion section (section 7.7).

7.2 Experiment 8

Experiment 8 was identical in design to Experiment 3, with two major exceptions. The first was that a toy figure called Hans (used in Experiment 7) was added as another character. The number of objects remained the same as in the first three experiments, and the objects belonged to Hans and Teddy in the experimental condition, or to Simba in the control condition. Both age-groups were used: hence 3-year-olds watched two characters and three toys tidied away, and 4-year-olds watched two characters and four toys tidied away. The second way that Experiment 8 differed from Experiment 3 was that the order of object tidying and probing in Experiment 8 was *TH123(4),* (tidying order) and *123(4)TH* (probing order), where *H* denotes the recall of Hans' location. This order therefore mirrored the order of object probing in Experiments 1 and 2 (see Table 5.1). Note that with the first three experiments, Teddy was tidied first and his location was probed last, after all the objects. However, in this experiment, although as a character his location is probed after that of the objects, the probing for his location is before that of Hans, so that as with the set of objects, the order of probing the characters proceeds in the same order as they are hidden.

7.2.1 Method

7.2.1.1 Design

The design was identical to Experiment 3, except that the Character condition now contained two characters and the Object condition had these as two extra toys, and there was thus an additional dependent variable for remembering the location of the second character. The Character condition was renamed *Two-C* and the Object condition was renamed *Two-C Simba.* The possible hypotheses concerning memory for the characters and object locations were discussed above, but an additional hypothesis is that Working Memory scores (memory for object locations) should be better in 4-year-olds than 3-year-olds.

7.2.1.2 Participants

Individual participants were different to those used in previous experiments, but also consisted of 3- and 4-year-old pre-school children from a number of local North London nurseries. As with Experiments 1 to 3, there were 28 four year olds (2 in each of the 7 randomisations for the 2 conditions) and 28 3-year-olds (2 in each of the 7 randomisations for the 2 conditions). The mean ages were 3;6 (range 3;3 to 3;12) and 4;4 (range 4;1 to 4;11).

7.2.1.3 Apparatus

The apparatus was as employed in Experiments 2 and 3, with the addition of Hans who had already been used in Experiment 7 (see section 6.11.1.3).

7.2.1.4 Procedure

The basic procedure followed the design of Experiment 3, apart from the order of testing the objects, which proceeded in the order of tidying - as in Experiments 1 and 2 (see Table 5.1). The main difference in the design involved the addition of an extra character for the Two-C conditions, and of an extra toy for Simba in the Two-C Simba conditions. These two conditions will be dealt with separately.

1. Two-C Condition

The procedure began in the same way as that of the Character condition in Experiment 3, except that instead of being introduced to just Teddy, the subject was introduced to Teddy and Hans (i.e. subjects were told they would be playing with "these two fellows" and were asked to shake their hands/paws). Subjects were told that the pile of toys (objects) belonged to both characters and that they would be inspected a little later on. The procedure continued as in Experiment 3, except that the digit span task with Teddy was replaced with a digit span task with Teddy and Hans. Hence the children were told that Teddy and Hans were good friends and that they phoned each other all the time. They were then told to repeat their phone-numbers in the same way as in Experiment 3, using "friends" numbers as well. Digit span was established according to the criterion documented in Experiment 1 (see section 4.2.1.4). The procedure continued as in Experiment 3, and instead of just Teddy feeling tired and going to sleep before the toys were tidied, both Hans and Teddy are tired and go to sleep, but in different receptacles, as dictated by the randomisation. The order of going to sleep was always Teddy followed by Hans. The procedure then continued as in Experiment 3, except that at probing, the object locations were probed in the order of hiding, and subjects were then asked where Teddy was sleeping, followed by being asked where Hans was sleeping.

2. Two-C Simba Condition

The procedure was identical to Experiment 3, except for two major alterations. First, Hans was an addition to the pile of Simba's existing three toys for 3-year-olds, or four toys for 4-year-olds. Note that Teddy also featured as a toy in the pile for both age-groups making a total of five toys for 3-year-olds, and six toys for the 4-year-olds. During the naming phase, most children named Hans as Simba's "boy", but "man", "dolly" and "girl" were also accepted. Emu tidied up Simba's toys as in Experiment 3, but after tidying up the Teddy, Hans was also tidied into a separate receptacle, followed by the rest of the toys. Hence the tidy order matched the Two-C condition *(TH123(4))*. The probe order also matched that of the Two-C condition *(123(4)TH)*. After location probing, digit span was elicited by using Teddy and Hans, who "come to life" when the subject searches for them in the receptacle set. As was the case in Experiment 3, the subjects were administered the same digit span procedure as subjects in the parallel control condition.

7.3 Experiment 9

In Experiment 9, the effect of further loading the Current State Buffer with a third character, is explored. The resulting set of data will thus allow a full analysis of Current State Buffer performance with the Current State Buffer loaded with one, two and three characters. Similarly, character load effects on Working Memory performance can be investigated.

7.3.1 Method

7.3.1.1 Design

The design was identical to Experiment 8, except that the Two-C condition now contained three characters, and therefore there was an additional dependent variable for remembering the location of the third character. The Two-C condition was renamed *Three-C* and the Object condition was renamed *Three-C Simba.* The possible hypotheses were discussed above.

7.3.1.2 Participants

Individual participants were different to those used in previous experiments, but also consisted of 3- and 4-year-old pre-school children from a number of North London nurseries. As with the last set of experiments there were 28 four year olds (2 in each of the 7 randomisations for the 2 conditions) and 28 3-year-olds (2 in each of the 7 randomisations for the 2 conditions). The mean ages were 3;5 (range 3;0 to 3;10) and 4;2 (range 4;1 to 4;4).

7.3.1.3 Apparatus

The apparatus was identical to that employed in Experiments 8, with the addition of *Bunny*, a small rabbit figure who was similar in size to Teddy and Hans (see photograph in Appendix 4). Bunny is pictured in Photograph 7.2.

Photograph 7.2: Bunny

7.3.1.4 Procedure

The procedure was essentially identical to the one employed in Experiment 8. The only differences resulted from the addition of Bunny as either another character (Three-C condition) or another object (Three-C Simba condition).

1. Three-C Condition

In the Three-C condition, Bunny featured as another character, along with Hans and Teddy. The procedure matched Experiment 8, except that the subject was now introduced to the three characters, and told that they were all best friends, and as a part of the initial interaction, the subject watched the three characters play "ring-a-ring -a-roses". The digit span task proceeded as in Experiment 8, except that Bunny now also has a telephone number, and his number and his friends numbers were rotated with the other telephone numbers (Teddy, Hans and their friends' numbers) in a random fashion, and digit span was established as in Experiment 8. Bunny went to sleep after Hans, and the object tidying order matched that of Experiment 8 (hence the tidying order was *THB123(4))*. The probing order also matched that of Two-C condition, with the addition of asking for Bunny's location following Hans' location item (hence the probing order was *123(4)THB)*.

2. Three-C Simba Condition

In the Three-C Simba condition the procedure was identical to Experiment 8's Two-C Simba condition, except that Bunny featured in the pile of objects with Simba's other toys. He was named by the subjects as a "Rabbit" or as a "Bunny Rabbit", and he was tidied away by Emu after Teddy and Hans and before the objects (hence the tidying order was *THB123(4)).* The tidying order thus matched the Three-C condition. The probing order also matched that of Three-C condition, with Bunny's location asked for as the last item (hence the probing order was *123(4)THB).* The digit span task was administered at the end of the trials using the same technique used with subjects in the Three-C conditions.

7.4 Results of Correct Responses in Experiments 8 and 9

The total number of correct "object" responses for each participant was collected (out of the number of objects paired excluding the character pairings). In addition, the number of character locations that subjects recalled correctly were recorded, and this was out of two in Experiment 8, and out of three in Experiment 9. A rough estimate of Working Memory was thus calculated as being equal to the object scores for the Two-C and Three-C conditions, and equal to the object plus the characters scores for the Two-C Simba and Three-C Simba conditions. *Overall Performance* is a figure calculated from the sum of subjects' object and character scores.

The mean of these three dependent variables for Experiments 8 and 9 are tabulated below in Table 7.1 for the 3-year-olds and in Table 7.2 for the 4-year-olds. In each table, the average performance of a *one Character* condition is also presented, and this is derived from the averages of correct object, character and Working Memory performance across the first three experiments for both age groups. Standard deviations are shown in brackets; for each cell in the "one Character" condition, n = 42, and for Experiments 8 and 9, each cell has n = 14.

In section 7.4.1 I will first present four separate ANOVAs computed on the four dependent variables, taking the two age-groups together. Following this I shall use these ANOVAs to examine the performance in the two age-groups separately (3-year-olds in section 7.4.2, and 4-year-olds in section 7.4.3).

7.4.1 Comparison of 3- and 4-Year-Olds

7.4.1.1 Performance on Character Locations

A three-way ANOVA with condition, age and number of characters (two or three[36]) as between subjects factors was conducted on correctly recalled character scores. This

[36] The one Character conditions were not included in this analysis because the variance of both 3- and 4-year-olds subjects in these Character conditions was zero - which not only violates an assumption of

TABLE 7.1 MEAN CORRECT OBJECT, CHARACTER, WORKING MEMORY AND OVERALL PERFORMANCE FOR 3-YEAR-OLDS IN EXPERIMENTS 8 AND 9

No. of characters and Experiment	Condition	object locations/3	character location(s)	Working Memory score	Overall Perf.
one Character:	Character	1.95 (1.03)	1.00 (0.00)	1.95 (1.03)	2.95 (1.03)
Experiments 1-3	Object	1.16 (1.03)	0.43 (0.43)	1.57 (1.25)	1.59 (1.23)
two Characters:	Two-C	2.00 (1.18)	1.57 (0.51)	2.00 (1.18)	3.57 (1.40)
Experiment 8	Two-C Simba	1.07 (0.73)	0.64 (0.63)	1.71 (1.14)	1.71 (1.14)
three Characters:	Three-C	1.21 (1.05)	1.21 (1.12)	1.21 (1.05)	2.43 (1.03)
Experiment 9	Three-C Simba	1.07 (0.83)	0.64 (0.75)	1.71 (1.38)	1.71 (1.38)

"Overall Perf." is Overall Performance. Standard deviations are in brackets. Data for two and three Character conditions are presented together with averaged figures for one Character, from Experiments 1-3.

revealed an effect of condition ($F_{(1,104)} = 26.68$, sig., $p < 0.001$) and an effect of the number of characters ($F_{(1,104)} = 4.17$, sig., $p < 0.05$), but failed to reach significance for age ($F_{(1,104)} = 1.74$, n.s.). There were no interaction effects ($F_{(1,104)} < 1$, n.s.). It should be noted that there was a consistent trend in Experiments 8 and 9 for the character scores of the older subjects in the Character conditions to be higher.

ANOVA, but means that the true difference in age-related performance cannot be measured since scores were at ceiling.

TABLE 7.2 MEAN CORRECT OBJECT, CHARACTER, WORKING MEMORY AND OVERALL PERFORMANCE FOR 4-YEAR-OLDS IN EXPERIMENTS 8 AND 9

No. of characters and Experiment	Condition	object locations/3	character location(s)	Working Memory score	Overall Perf.
one Character:	Character	2.60 (1.17)	1.00 (0.00)	2.6 (1.17)	3.60 (1.17)
Experiments 1-3	Object	1.62 (1.32)	0.48 (0.51)	2.10 (1.49)	2.10 (1.49)
two Characters:	Two-C	2.21 (1.12)	1.86 (0.36)	2.21 (1.12)	4.07 (1.27)
Experiment 8	Two-C Simba	1.71 (1.38)	1.00 (0.78)	2.71 (1.68)	2.71 (1.68)
three Characters:	Three-C	1.86 (1.01)	1.36 (1.08)	1.86 (1.01)	3.21 (1.42)
Experiment 9	Three-C Simba	1.57 (1.28)	0.64 (0.75)	2.21 (1.25)	2.21 (1.25)

"Overall Perf." is Overall Performance. Standard deviations are in brackets. Data for two and three Character conditions are presented together with averaged figures for one Character, from Experiments 1-3.

The frequencies of correct responses for the different characters in the two studies are shown below in Table 7.3. It should be noted that the location of no one character is markedly better recalled than any other.

7.4.1.2 Working Memory Performance

A three-way ANOVA with condition, age and number of characters (one, two and three) as between subjects factors was conducted on Working Memory scores. This revealed an effect of age ($F_{(1,268)} = 11.64$, sig., $p < 0.0008$) but did not reveal a significant effect for condition ($F_{(1,268)} < 1$, n.s.) or number of characters ($F_{(1,268)} = 1.63$, n.s.). The analysis revealed that the interaction effect between the number of characters and condition was almost significant ($F_{(1,268)} = 2.81$, n.s.,

TABLE 7.3 FREQUENCIES OF SUBJECTS RECALLING THE CORRECT LOCATIONS OF THE DIFFERENT CHARACTERS IN EXPERIMENTS 8 AND 9

	3-Year-Olds				4 -Year-Olds			
	Experiment 8		Experiment 9		Experiment 8		Experiment 9	
	Ch	Obj	Ch	Obj	Ch	Obj	Ch	Obj
Teddy	12	4	6	5	14	7	5	4
Hans	10	5	4	2	12	7	7	2
Bunny	-	-	7	2	-	-	7	3

Character and Object conditions are denoted by "Ch" and "Obj" respectively. Each cell's frequency is out of a possible 14 subjects.

$p = 0.062$), which when inspected, showed that taking both age-groups together[37], the Three-C conditions had significantly lower Working Memory performance than the other Teddy as Character conditions ($F_{(1,268)} = 4.36$, sig, $p < 0.05$. The parallel difference was not evident in the "Object" conditions ($F_{(1,268)} < 1$, n.s.). No other interaction effects were significant ($F_{(1,268)} < 1$, n.s.).

7.4.1.3 Performance on Object Locations

A three-way ANOVA with condition, age and number of characters (one, two and three) as between subjects factors was computed on the object scores for all age-groups. This revealed a main effect of condition ($F_{(1,268)} = 15.38$, sig., $p < 0.002$) and age ($F_{(1,268)} = 11.25$, sig., $p < 0.001$), but just missed significance for number of characters($F_{(1,268)} = 2.7$, n.s., $p = 0.07$). No interaction effects were significant ($F_{(1,268)} < 1.82$, n.s.).

7.4.1.4 Overall Performance

A three-way ANOVA with condition, age and number of characters (one, two and three) as between subjects factors was conducted on Overall Performance scores. This revealed an effect of condition ($F_{(1,268)} = 51.10$, sig., $p < 0.001$), age ($F_{(1,268)} = 3.48$, sig., $p < 0.05$) and number of characters ($F_{(1,268)} = 51.10$, sig., $p < 0.001$). No interaction effects were significant ($F_{(1,268)} < 1.3$, n.s.).

[37] Although this section is supposed to deal with comparisons between age-groups, this contrast is reported in this section because it follows neatly from this particular ANOVA.

7.4.1.5 Summary

Subjects in the Character conditions recalled more character locations than subjects in the Object conditions, and as the number of characters to be recalled increased, this generally had an effect of increasing the number of characters recalled for subjects in both conditions.

The 4-year-old subjects had higher Working Memory scores than their 3-year-old counterparts. There were no differences in Working Memory performance between conditions in the experiments, except that there was evidence that subjects in the Three-C conditions had lower Working Memory performance scores than the other Teddy as Character conditions.

For performance on object locations and on Overall Performance, subjects in the Character conditions had better scores than subjects in the Object conditions, and the 4-year-olds had higher scores than the 3-year-olds.

7.4.2 The 3-Year-Olds

7.4.2.1 Character Scores

Since there was an effect of condition on character scores, as reported above (section 7.4.1.1) in the three-way ANOVA, planned comparisons were computed, revealing a significant difference between the Two-C and Two-C Simba conditions ($F_{(1,104)} = 9.75$, sig., $p < 0.003$) and just failing to reach significance for the difference between the Three-C condition and Three-C Simba condition ($F_{(1,104)} = 3.69$, n.s., $p = 0.056$).

For each of the two experimental conditions in this age-group, separate analyses were carried out to compute whether the increase in the number of characters had resulted in a change in character location performance. Non-parametric techniques were employed for exploring the increase in character performance from one character to two characters, because the data for the one Character conditions had a standard deviation of zero. The increase from two to three characters will be dealt with separately in a parametric fashion, using the three-way ANOVA that I reported in section 7.4.1.1.

1. Increasing one to two Characters

Mann Whitney U tests revealed that there was a significant increase in character location performance in the Character conditions ($U = 126$, $N_1 = 42$, $N_2 = 14$, sig., $p < 0.001$), but not in the Object conditions ($U = 243$, $N_1 = 42$, $N_2 = 14$, n.s.).

Note that performance was no longer at ceiling level for the Two-C condition, when the character load was increased beyond one character.

2. Increasing two to three Characters

As mentioned above (in section 7.4.1.2), the three-way ANOVA on character scores revealed an effect of number of characters pooled across both age groups when increasing character load from two to three. When this decrease in character location scores for just 3-year-olds was computed as a simple effect, this showed that the decrease was not significant ($F_{(1,104)} = 1.44$, n.s).

7.4.2.2 Working Memory Scores

As reported above (section 7.4.1.2) in the three-way ANOVA on Working Memory scores, there was no difference in scores between Character and Object conditions on Working Memory performance. However, as I mentioned, inspecting the significant interaction between number of characters and condition revealed that with both age groups pooled together there was a significant decrease in Working Memory performance with three characters relative to one and two for the "Character" conditions only. This contrast was therefore computed for just 3-year-old "Character" subjects, revealing that the simple effect was significant ($F_{(1,268)} = 3.86$, sig., $p < 0.05$).

7.4.2.3 Object scores

The difference in performance between the subjects in the Object and Character conditions for 3-year-olds in Experiments 8 and 9 were inspected by calculating simple effects in the three-way ANOVA on object scores reported above in section 7.4.1.5. This revealed a significant difference in Experiment 8 between the Two-C and Two-C Simba conditions ($F_{(1,26)} = 4.73$, sig., $p < 0.05$), but no significant difference between the Three-C and Three-C Simba conditions in Experiment 9 ($F_{(1,268)} < 1$, n.s.).

7.4.2.4 Overall Performance Scores

Planned comparisons on just the 3-year-olds' Overall Performance scores were computed from the three-way ANOVA reported in section 7.4.1.4 for the one, two and three Character conditions. These compared the difference in Overall Performance between the "Character" and "Object" conditions. The simple effects were significant for the one Character ($F_{(1,268)} = 21.74$, sig., $p < 0.001$) and two Character conditions ($F_{(1,268)} = 13.56$, sig., $p < 0.001$), but failed to reach significance in the three Character condition ($F_{(1,268)} = 2.0$, n.s.).

7.4.2.5 Summary

The Two-C Simba condition recalled less of the character locations than did the Two-C condition, and this difference was evident between the Three-C and Three-C Simba conditions. The performance on character locations by the 3-year-old subjects in the Character condition had increased to correctly recalling one and a half locations, when tracking two characters. When tracking three characters however, there was a drop in performance.

Working Memory performance had dropped in the Three-C condition relative to the other Character conditions. Similarly, there was a difference between Character and Object conditions on object scores and Overall Performance in the one and two Character conditions, but not in the three Character conditions.

7.4.3 The 4-Year-Olds

7.4.3.1 Character Scores

Since there was an effect of condition on character scores, as reported above in the three-way ANOVA in section 7.4.1.1, planned comparisons were computed, revealing a significant difference between the Two-C condition and Two-C Simba condition ($F_{(1,104)} = 8.31$, sig., $p < 0.004$) and a significant difference between the Three-C condition and Three-C Simba condition ($F_{(1,104)} = 5.77$, sig., $p < 0.018$).

For both of the experimental conditions separate analyses were carried out to compare whether the increase in the number of characters had resulted in a change in performance. Non-parametric techniques were employed for exploring the increase in character performance from one character to two characters, because the data for the one Character conditions had a standard deviation of zero. The increase from two to three characters will be dealt with separately in a parametric fashion, using the three-way ANOVA discussed above in section 7.4.1.1.

1. Increasing one to two Characters

Mann Whitney U tests revealed that there was a significant increase in character location performance in the Character conditions ($U = 42$, $N_1 = 42$, $N_2 = 14$, sig., $p < 0.001$), and in the Object conditions ($U = 184$, $N_1 = 42$, $N_2 = 14$, sig., $p < 0.04$). Note that performance was just below ceiling level for the 4-year-olds in the Two-C condition, when the character load was increased.

2. Increasing two to three Characters

As mentioned above, the three-way ANOVA on character scores revealed an effect of number of characters pooled across both age groups when increasing character load from two to three. When this decrease in mean character score was computed as a simple effect for just the 4-year-olds, this decrease just missed significance ($F_{(1,104)} = 2.83$, n.s., $p = .10$).

7.4.2.2 Working Memory Scores

As reported above in the three-way ANOVA on Working Memory scores (section 7.4.1.2), no difference in scores was found between Character and Object conditions on Working Memory performance. However, on inspection of the significant interaction between the number of characters and condition, it was found that with both age groups pooled together there was a significant decrease in Working Memory performance when tracking three characters relative to one and two for the "Character" conditions only. This contrast was therefore computed for just 4-year-olds, but it did not reveal a significant simple effect ($F_{(1,268)} = 2.0$, n.s.). A slightly different contrast was thus computed, comparing the Teddy as Character groups of the one Character with the two and three Character experimental (Teddy as Character) groups. This simple effect just failed to reach significance, with $F_{(1,268)} = 3.33$, n.s., $p = 0.068$.

7.4.3.3 Object Scores

The difference in performance between the Object and Character conditions for 4-year-olds in Experiments 8 and 9 were inspected by calculating simple effects in the three-way ANOVA on object scores reported above in section 7.4.1.3. This revealed that there was no significant difference in Experiment 8 between the Two-C and Two-C Simba conditions ($F_{(1,26)} = 1.37$, n.s.), and no significant difference between the Three-C and Three-C Simba conditions in Experiment 9 ($F_{(1,268)} < 1$, n.s.).

7.4.3.4 Overall Performance Scores

Planned comparisons on just the 4-year-olds' Overall Performance scores were computed from the three-way ANOVA reported above (in section 7.4.1.4) for the one, two and three Character conditions. These compared the difference in Overall Performance between the "Character" and "Object" conditions. The simple effects were significant for the one Character ($F_{(1,268)} = 26.56$, sig., $p < 0.001$) and two Character conditions ($F_{(1,268)} = 7.25$, sig., $p < 0.008$), and also in the three Character condition ($F_{(1,268)} = 3.93$, sig., $p < 0.05$).

7.4.3.5 Summary

As with the 3-year-olds, the 4-year-olds in the Two-C Simba condition recalled less of the character locations than did the Two-C condition, and this difference was evident between the Three-C and Three-C Simba conditions. The 4-year-olds however, coped better than the 3-year-olds in having to track two characters, and performed at almost ceiling level, but when tracking three characters, their performance dropped by about half a character location.

There was a steady drop for the 4-year-old subjects in Working Memory performance as the number of characters to be tracked increased, but Overall Performance was better for subjects in the Character condition relative to subjects in the Object condition across all three character loads.

7.5 Receptacle Confusion Errors in Experiments 8 and 9

Thus far, the dependent variable has been the strict measure of whether, when probed for the location of a given stimulus, subjects remember the correct item in the correct location. However, error data is also a useful adjunct to this. Presented below in Table 7.4 are the location errors made by subjects in Experiments 8 and 9. Totals are given separately for all errors *(Total Error)* on character and object locations. These can then be further divided into the type of error made on the basis of the basis of these two categories of items. Hence there are character locations confused with the locations another character *(C-c)*, character locations confused with location of an object *(C-o)*, object locations confused with the location of an object *(O-o)*, and object locations confused with the location of a character *(O-c)*.[38]In Table 7.4 these sub-categories of errors are given as proportions of the total character location errors (for C-c and C-o) and object location errors (for O-o and O-c).

The left-hand-side of the table, which pertains to errors made on character locations is useful in identifying the fine-grained detail of Current State Buffer function when it is loaded beyond capacity. As reported above in Experiment 9 (section 7.4.2.1), the scores on correct character locations did not differ significantly between experimental conditions for the 3-year-olds, as they have done in studies using just one or two characters. For this reason, it is important to examine the 3-year-old subjects' character location performance Experiment 9.

[38] In the Appendix 3, the total errors (i.e. not divided into character and object location errors) in Experiments 8 and 9, together with the class of error as a proportion, can be found. This includes C-e and O-e which are the character location errors and object location errors respectively, that indicate a "don't know" or a confusion of a location with a non-used receptacle.

TABLE 7.4 ERRORS OF SUBJECTS IN EXPERIMENTS 8 AND 9.

			Character Probe Responses			Object Probe Responses		
			TOTAL ERROR	Type of character error as proportion		TOTAL ERROR	Type of object error as proportion	
Age	Exp	Cond	Errors on character locations	C-c	C-o	Errors on object locations	O-o	O-c
3	8	Ch	0.43	0.00	0.50	1.00	0.38	0.17
3	8	Obj	1.34	0.08	0.61	1.93	0.35	0.36
3	9	Ch	1.79	0.71	0.19	1.79	0.29	0.63
3	9	Obj	2.36	0.33	0.48	1.93	0.19	0.46
4	8	Ch	0.14	0.00	0.50	2.43	0.51	0.04
4	8	Obj	1.00	0.35	0.50	2.57	0.30	0.32
4	9	Ch	1.64	0.50	0.50	2.21	0.69	0.32
4	9	Obj	2.36	0.48	0.52	2.64	0.32	0.55

Errors are either on character or object locations, and the nature of these errors are given as proportions of the relevant error total. "Ch" and "Obj" refer to Character and Object conditions respectively. Other abbreviations are defined in the text.

The C-c column in Table 7.4 displays a tendency for subjects to confuse character locations, and the C-o column a tendency to attribute object locations to characters. Let me draw attention to the shaded region of Table 7.4. It should be noted that for the 3-year-old subjects in the Character condition of Experiment 9, the distribution of the proportion of character errors that are C-c relative to C-o are in a ratio of almost 4 to 1. This is in comparison to the Object condition of Experiment 9, where the C-o errors are *greater* than the C-c errors, although the ratio is much smaller. In order to try to explore this difference in error distributions between conditions statistically, the total frequency of subjects who made more C-c errors than C-o errors was investigated in each condition. This was then compared with the frequency of the number of subjects who made more C-o errors than C-c errors[39]. The resulting contingency table is displayed below in Table 7.5. In this way the data had been transformed into nominal data, and since two independent groups are being compared a Chi Squared test is an appropriate way of testing this difference in error patterns. A standard Chi squared test revealed a significant difference with $\chi^2 = 5.84$ (df = 1, p = 0.012), and with a Yates corrected test, the statistic was $\chi^2 = 3.74$ (df = 1, p = 0.053).

TABLE 7.5 FREQUENCY OF 3-YEAR-OLDS SUBJECTS IN EXPERIMENT 9 SHOWING THE DISTRIBUTION OF INTER- AND INTRA-CATEGORY TYPE ERRORS MADE ON CHARACTER LOCATIONS.

Condition in Experiment 9	**Number of subjects where C-c greater than C-o**	**Number of subjects where C-o greater than C-c**
Three-C condition	**8**	**1**
Three-C Simba condition	**3**	**6**

See text for abbreviations

For the 4-year-olds in Experiment 9, it can be seen from Table 7.4 that the proportion of types of character location error are shared evenly between the C-c and C-o classes in both the Character and the Object conditions. This seems to indicate that although the 3-year-olds made same category errors on character locations, the 4-year-olds did not display this pattern of responding.

7.6 Digit Spans in one, two and three Character Conditions

Table 7.6 below displays the digit spans of subjects in the one, two and three Character conditions (Experiments 1 to 3, and Experiments 8 an 9). Note that the mean of the digit span scores for one Character subjects has been taken as the average across Experiments 1 to 3.

A three-way ANOVA, with age, condition and number of characters as independent variables was computed on digit span. This revealed a main effect of age ($F_{(1,268)} = 46.55$, sig., $p < 0.001$), but not for condition ($F_{(1,268)} < 1$, n.s.) or

[39] Where the two types of error were equal in number, the subject's data was not included. "Don't knows" and non-used receptacles were discounted in all subjects when determining which of the error categories were in the majority.

number ($F_{(1,268)} < 1.71$, n.s.).of characters ($F_{(1,268)} = 2.28$, n.s.). No interaction effects were significant

TABLE 7.6 DIGIT SPANS OF SUBJECTS IN ONE, TWO AND THREE CHARACTER CONDITIONS

		3-Year-Olds	4-Year-Olds
No. of Characters and Experiment	**Experimental Condition**	**Digit Span**	**Digit Span**
one Character:	**Character**	**3.33**	**4.31**
Experiments 1-3	**Object**	**3.20**	**4.26**
two Characters:	**Two-C**	**3.68**	**4.14**
Experiment 8	**Two-C Simba**	**3.28**	**4.61**
three Characters:	**Three-C**	**3.54**	**4.86**
Experiment 9	**Three-C Simba**	**3.68**	**4.39**

All cells have n = 14 except the one Character cells, n = 42.

7.7 Discussion

7.7.1 Age Differences in Working Memory

In trying to summarise the above results, there are a few clear findings. Working Memory performance is superior in 4-year-olds relative to 3-year-olds, which reflects the expected increase in Working Memory in general and the Visuospatial Sketchpad in particular. For this type of visuospatial task, the age-related difference seems to be around one half of an item location.

It is of importance to note that in the three-way ANOVA reported in section 7.4.1.2 there was only a main effect of age on Working Memory, and no overall effect of experimental condition on Working Memory - which approximates to the assumption that subjects in the two conditions of each age-group would have equal Working Memory capabilities. This age-related shift in Visuospatial Sketchpad performance is complemented by the increase in Phonological Loop span of about one digit, as indexed by the digit span task (-the normative data from the digit span task were consistent with those of Chi (1978)). The ANOVA on digit span (section 7.6) also demonstrated that subjects in the Character condition did not differ from subjects in the Object condition on performance in this task, again indicating that subjects in the two conditions did not differ in general Working Memory capacity.

7.7.2 Character Location Performance

One of the aims of the present chapter was to explore the capacity of the Current State Buffer. From the results at hand, it seems that the capacity of the Current State Buffer for character locations in the Tidy Emu Paradigm is just over one and a half for 3-year-olds, and just below two for 4-year-olds. The possibility that subjects are able to track as many characters as they are given can be clearly ruled out.

However, an obvious question is why character location performance should drop in the Three-C condition in Experiment 9 relative to the Two-C condition in Experiment 8, if the capacity of the Current State Buffer is reached with only two characters. Although the drop in performance was not statistically significant for the individual age-groups (see section 7.4.2.1 for 3-year-olds, and 7.4.3.1 for 4-year-olds), the fact that it was found for both age-groups (see main effect of number of characters on correct character locations in section 7.4.1.1) is taken as an important trend. One of the possible answers to this question may have been that in Experiment 9, one of the characters was more salient than the others, leading to increased recall of that character and depressed recall of the others. From inspection of the distribution of correct responses in Table 7.3 this can be ruled out, and a different avenue of enquiry can be made.

The three-way ANOVA on character scores (section 7.4.1.1) revealed that subjects in the Character conditions have better character performance relative to subjects in Object conditions. However, simple effects demonstrated that this was only so for the one and two Character conditions. In which case, it seems reasonable to assume that the advantage of being in the Character condition breaks down when tracking three characters. An account for this pattern of data may be that subjects in the Three-C conditions, when trying to track three characters, suffer from catastrophic interference in their Current State Buffers due to the overload, and their performance drops to below capacity. This account may explain the effect on the Current State Buffer when character load increases from two to three characters; but how does it relate to the effects on Working Memory that result from an increase in character load?

7.7.3 Working Memory Performance

A clue to answering this may be gleaned from scrutiny of the three-way ANOVA on Working Memory performance (section 7.4.1.2). This revealed that performance had decreased in both age-groups in Experiment 9 for subjects in the Character conditions, but not for subjects in the Object conditions. Increasing character load therefore affected Working Memory performance, even though the explicit Working Memory load stayed constant in Experiments 8 and 9.

7.7.3.1 The 3-Year-Olds

For the 3-year-olds, the above account fits in well with this finding; and particularly because the relevant simple effect showing a decrease in Working Memory performance when tracking three characters is also significant (see section 7.4.2.2). As a result of the catastrophic interference introduced by the third character, the Current State Buffer is put under such stress that resources from Working Memory are deployed in order to accommodate tracking the extra character. As a consequence of this, Working Memory performance drops in Experiment 9 for the Three-C condition and not for the Three-C Simba condition.

What also bolsters this explanation is the lack of difference on object location performance[40] between the Three-C condition and the Three-C Simba condition, that was evident when subjects had to track just one or two characters. The subjects in the Object conditions had to remember more objects and this resulted in interference. If the usual Character condition advantage has disappeared when tracking three characters in Experiment 9 then this hints that these subjects' Visuospatial Sketchpads are also being over-stretched, albeit for a different reason.

If the increase in character load lead to catastrophic interference, with the result that resources were deployed from Working Memory, then it is pertinent to ask whether Current State Buffer function was totally impaired. In order to tackle this question, the receptacle confusion errors can answer what Two-C condition subjects were responding when probed for characters. If their decreased Overall Performance was coupled with many character-character location errors, and relatively few character-object location errors, then this would imply that these subjects are at least coding for "character locations", but not for specific characters in a given character location. Indeed this pattern of data was reported in section 7.5 and provides evidence that although the 3-year-olds are not performing so well on correct specific character locations, they are able to remember the receptacles where the characters are hidden.

[40] And equally on Overall Performance.

In sum, this suggests an interesting approach taken by 3-year-olds when their Current State Buffers are overloaded with a third character. Rather than just track two characters (and "ignore" the third), the importance of the status of the characters leads to a shift in strategy in which subjects recall the character locations as a set without regard to individual characters. I have also suggested that the 3-year-olds benefit from an influx of resources that have been deployed from Working Memory. In this way their immature meta-cognitive skills are exposed since they lose sight of the task demands, as they are sacrificing performance on recalling the locations of the objects, which in fact the experimenter has instructed them to remember. What they gain from this sacrifice is coding the set of receptacles that the characters inhabit - something that they have not been told to do.

7.7.3.2 The 4-Year-Olds

The story for the 4-year-olds is somewhat different as they have better meta-cognitive skills and larger capacity buffers. Their Overall Performance is not sacrificed, to which the ANOVA on Overall Performance attests, in there still being a difference between Character and Object conditions with one, two and three characters. The 4-year-olds in the Character conditions similarly maintain an advantage over the 4-year-olds in the Object conditions on character location performance. So although there may be a little catastrophic interference in the 4-year-olds' Current State Buffers with a third character, their Current State Buffer capacities are sufficiently large to withstand the full blow of the detrimental effects of overload from a third character.

It will be recalled that there is a more steady drop in Working Memory performance in the 4-year-old Character conditions (compared with the sudden drop in 3-year-olds subjects in Experiment 9), and that they did not display a receptacle confusion error pattern in the way that the 3-year-old Three-C condition subjects did. The drop in 4-year-old subjects' Working Memory performance took away the advantage of Character condition subjects on object locations, as the character load was increased (see section 7.4.3.3). This may be indicative of a more mature system that has the meta-cognitive capabilities to adapt to the increasing needs of the Current State Buffer. As the Current State Buffer is incrementally loaded with characters, Working Memory then allocates enough resources to successfully code the actual item-location pairing of characters without interfering as drastically with task demands. It is quite probable that with four characters, the 4-year-olds would produce a data set equivalent to the 3-year-olds with three characters. Hence task demands would not be adhered to, resulting in lower Working Memory performance, and specific character location performance would be reduced, but general character location performance as a set would not be impaired.

7.8 Conclusion

From the data presented in the chapter, it seems that the 3-year-olds can only deal with tracking one character, whereas the 4-year-olds can more or less manage two characters. After the subjects in the Character conditions tracked one character perfectly in the earlier experiments in this thesis, the addition of one extra character produces interference for them (particularly for 3-year-olds), and the addition of two extra characters results in catastrophic interference

In this chapter, the effect of increasing character load using the Tidy Emu Paradigm has proved to be an informative exercise. It has revealed the precise capacities of the Current State Buffer for the different age-groups. Similarly, it has been shown how the effects of catastrophic interference in the Current State Buffer are differentially dealt with by the two age-groups in terms of differences in meta-cognitive strategies and the re-allocation of Working Memory resources.

CHAPTER 8

Conclusions

8.1 Chapter Outline

In this final chapter, I begin by summarising the main components and studies contained within this thesis (section 8.2). Then I proceed to consider specific limitations of some of the arguments that I have made (section 8.3). Following this, I consider the inter-relationships between the Current State Buffer and Working Memory (section 8.4), and the issue of the capacity of the Current State Buffer (section 8.5). Finally, before concluding, I briefly discuss the Current State Buffer and development (section 8.6).

8.2 Summary of Thesis

8.2.1 Working Memory and the Current State Buffer

This thesis began with a discussion of theories of Short Term Memory in Chapter 1, and presented the Working Memory model (Baddeley and Hitch, 1974) as a framework that explains a great deal of the short term memory phenomena that have been explored to date. The Working Memory model was then examined in relation to the development of Short Term Memory (Chapter 2). It was noted in Chapter 3 however, that the theory seemed to lack specification of a functionally vital component of any model of Short Term Memory; namely the capacity to automatically keep track of important stimuli in an individual's immediate personal environment. The Current State Buffer (Morton, 1997) was then discussed as a construct which fulfils this role, and which has already met with considerable experimental success as demonstrated by Barreau and Morton (in press).

8.2.2 The Tidy Emu Paradigm

I therefore started with the á priori assumption that the Current State Buffer exists as a separate entity from the specified components of Working Memory. The Tidy Emu Paradigm, which is based on dual-task methodology, was explicitly designed in order to test this basic premise. It constituted a visuospatial Working Memory task - remembering the location of objects in receptacles, concurrent with a Current State Buffer task - remembering the location of an animated Teddy in the same receptacle set. Pre-school children were selected as subjects in the paradigm because they do not phonologically recode spatial information. This ensured that object location storage would be restricted to the Visuospatial Sketchpad. Similarly, the Visuospatial

Sketchpad task was designed such that it loaded Working Memory to capacity, so that Working Memory could not be implicated in any way in contributing to the performance on the Current State Buffer component of the task.

8.2.3 Experiment 1

It is important to note that I formulated two clear hypotheses in Chapter 4 stemming from the fact that performance was predicted to show independence on the Current State Buffer and Working Memory tasks. The control group involved subjects remembering the same object locations plus the location of a non-animated Teddy. The predictions were a double-edged sword: the experimental condition would have superior performance on recall of Teddy's location, and of the object locations relative to the control group. This was because the subjects in the experimental condition would store Teddy's location in their Current State Buffers and the object locations in Working Memory. Subjects in the control condition would store all locations in an over-loaded Working Memory, and this would produce interference when recalling the objects' location and Teddy's location. The results of Experiment 1 supported both the experimental hypotheses, providing initial evidence for the independence of the Current State Buffer from Working Memory. What was impressive was not just that recall of Teddy's location was superior in the experimental condition, but that all the subjects in the condition recalled his location perfectly. Similarly, these subjects had not even been instructed to remember Teddy's location.

8.2.4 Alternative Explanations to Experiment 1: Experiments 2 and 3

Other explanations of this core finding were then carefully considered. Among these were the possibilities that the findings were explainable in terms of a von Restorff Isolation Effect (section 4.3.1), a Levels of Processing Effect (section 4.3.2), the effects of Organisation in memory (section 4.3.3), the effects of intentional and incidental learning (section 4.3.4), of Long Term Memory (section 4.3.5), and of phonological recoding at output (section 4.3.6). In Chapter 5, alternative options were tested experimentally and rejected (Experiment 2) and the findings of Experiment 1 were replicated: subjects in the experimental condition performed better both on recalling the object locations and Teddy's location (performance was at ceiling in the experimental condition again). Other explanations, including the possibility of multiple Recency effects (section 5.3.1) were considered in Experiment 3, and these too were rejected, and the findings of Experiments 1 and 2 were further replicated. Hence from a total of 168 subjects and two separate age-groups, it was clear that having to remember Teddy's location created no cost for subjects in the Teddy as Character condition, and all this had been predicted ex-hypothesi based on the existence of a Current State Buffer.

8.1.4.1 A Comment on Alternative Explanations

As I mentioned before, the findings of Experiments 1, 2 and 3 are pertinent because both recall of Teddy's location and the object locations were significantly better in the experimental conditions relative to the control conditions. Apart from the fact that these results were predicted by the theory, the strength of the Current State Buffer explanation lies in the fact that it accounts for the results as a pair. Any serious alternative explanation therefore needs to explain both aspects of the results. If a particular theory or explanation can account for only one half of the results, then for it to be valued as a viable alternative, it must also make sense of the other half of the findings. To illustrate this point, consider the following explanation of the success of Teddy as Character subjects on the recall of Teddy's location. Subjects were not incidentally remembering the location of Teddy, according to this explanation, but rather they intentionally rehearsed his location whilst the other objects were being hidden leading to better recall of his location. This account focuses solely on the recall of Teddy's location, and so much so that the account fails to recognise that since recall of the object locations is also due to intentional learning, then there is no reason to predict that there will be an advantage over subjects in the control condition where the learning is also all intentional.[41] Parenthetically, the other obvious weakness to this particular interpretation, is its mention of rehearsal - something that does not begin until seven years of age (e.g., Flavell et al., 1966).

8.2.5 Architecture of the System

Chapter 6 continued to use the Tidy Emu Paradigm to explore the Current State Buffer, since it had been established as independent of Working Memory. Various models of a system that housed the Current State Buffer and Working Memory were considered as possibilities in accommodating the data set from the previous chapters, and predictions were made based on the different architectures. Experiments 4, 5, 6 and 7 were thus empirical tests of the models using the Teddy as Character condition of the standard Tidy Emu Paradigm, but varying the input and output orders of the stimuli. In brief, the data are best described by an architecture where information enters an Environmental Input Buffer, and, depending on the nature of the stimulus, it passes either into the Current State Buffer or into an Interpreter Buffer (Working Memory). At retrieval, the contents of these buffers can independently proceed to an Output Buffer.

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[41] This explanation of the findings was suggested to me by the reviewer of a leading international journal of Psychology.

8.2.6 Multiple Characters

Chapter 7 reported Experiments 8 and 9, in which the character load was systematically increased. This allowed for an accurate measure of the capacity of the Current State Buffer, since until Chapter 7, its performance had been at ceiling level - tracking just one character. What became apparent was that when the 3- and 4-year-olds track two characters they approach their Current State Buffer capacities for this task at just over one and a half characters (3-year-olds) and just under two characters (4-year-olds). Tracking three characters however, produces catastrophic interference in subjects' Current State Buffers, and more markedly so for 3-year-olds. This was evident from the subsequent fall in character location performance in subjects from both age-groups when they track three characters. I discussed the age-related strategies of the two age-samples in dealing with this overloading, and importantly the role of Working Memory in deploying resources to the Current State Buffer when necessary. Chapter 7 also provided further evidence for the Visuospatial Sketchpad (Working Memory) performance differential expected between the two age-groups.

8.3 Possible Limitations

As I mentioned earlier, the Tidy Emu Paradigm was conceived with the specific goal of demonstrating the independence of Working Memory from the Current State Buffer and therefore certain constraints were intentionally built into the design. However, these constraints need consideration as they pose potential limitations on the work that I have reported in this thesis.

8.3.1 Only Visuospatial Representations have been Investigated

In order to restrict Working Memory representations to one sub-component of the system, a visuospatial task was selected with pre-school children as subjects, since they do not phonologically recode spatial representations. It could be argued therefore, that the findings cannot be generalised beyond visuospatial representations. This would mean that for the Current State Buffer to be fully recognised as independent from Working Memory, there would be a need to demonstrate its independence from the Phonological Loop.

What tempers this particular limitation is a close consideration of the findings from Experiments 1 and 2. It will be recalled that one of the differences between the two experiments was that in Experiment 1, subjects could vocalise their responses, whereas in Experiment 2 subjects were encouraged to point at receptacles so as to prevent any possibility of causing phonological recoding at output (see section 4.3.6). The change in procedure was to counter the argument that the results were not showing the independence of the Visuospatial Sketchpad and the Current State Buffer, but of the

Visuospatial Sketchpad and the Phonological Loop. Since the results of Experiment 1 were replicated in Experiment 2, this demonstrated retroactively that the Current State Buffer could not have been equivalent to that part of the system involved in the verbal output of responses.

What remains of this limitation relating to visuospatial representations however, is a valid issue that the results in the thesis cannot answer. This is that we still need enlightening as to whether phonological information in the Current State Buffer is independent from the Phonological Loop. A likely candidate for phonological representations that would enter the Current State Buffer may be mental states, in that they are certainly not visuospatial in nature.

8.3.2 Age-group

The developmental age-group was selected because of the reasons mentioned above pertaining to the Visuospatial Sketchpad as well as the fact that their less mature memory system is a more tractable substrate for investigating new constructs such as the Current State Buffer. The particular age-group was also appropriate because of the necessity for the Current State Buffer task to be automatic and therefore incidental. The result of this is that the task in its current format is limited in that it is only appropriate for 3- and 4-year-olds, and possibly 5- and 6-year-olds.

The theory predicts that independence of the Current State Buffer from Working Memory should in principle be possible to demonstrate experimentally with older children and adults. Isolating a Working Memory component task to the Visuospatial Sketchpad is not a problem since subjects can perform articulatory suppression whilst performing the visuospatial and Current State Buffer task. However, the major problem in designing experiments that will achieve this is finding a Current State Buffer task that maintains the automaticity of an incidental learning situation, while keeping the Current State Buffer stimulus important within the experimental design.

8.4 Relationship between Working Memory and the Current State Buffer

In Chapter 7, I discussed the way in which the Current State Buffer was found to interact with Working Memory. In the previous chapters, the case was made for the Current State Buffer being an independent entity to Working Memory. An issue here therefore, is the precise relationship between the Current State Buffer and Working Memory in terms of the existing architecture of the Working Memory model. What will follow in the next paragraph are a few thoughts, which remain speculative in nature, on possible relationships between the Current State Buffer and Working Memory. Note that one of the central arguments of the thesis has been that the Working Memory model has not accounted for Current State Buffer functioning in its specification to date. Thus whether the Current State Buffer ultimately becomes an integrated part of the current Working Memory model account, or whether it remains relatively independent to it, remains relatively peripheral to the thrust of the thesis.

An example of when the connectivity between the Current State Buffer and Working Memory becomes an issue arises from considering the effect of overloading the Current State Buffer with character locations, as in Chapter 7. For subjects in both age-groups, this lead to a decrease in Working Memory performance. It was suggested (in section 7.7.3) that there had been a re-allocation of resources from the Visuospatial Sketchpad into the Current State Buffer. A possible account for this is that when the Current State Buffer becomes overloaded, the additional character location or locations, cannot be registered in the Current State Buffer. The Central Executive may then be sensitive to the appearance of "floating" representations that have not been successfully entered into the Current State Buffer. This signals the Central Executive to deploy processing resources from the Visuospatial Sketchpad in order to help register and maintain the representation of the extra character locations. Hence with this conception, the Current State Buffer is only subject to the control processes of the Central Executive, in that it can receive support from the Visuospatial Sketchpad under the direction of the Central Executive.

In this account, however, it would not be the case that the Central Executive has the ability to pull resources from the Current State Buffer. So that if the Visuospatial Sketchpad became overloaded from additional object locations, and required help for maintenance of the additional representations, the Central Executive would be unable to obtain these resources from the Current State Buffer. The justification for this is that the representations in Current State Buffer are of higher priority, and therefore representations in the Current State Buffer must remain independent to Working Memory functioning in this sense.

Another rationale for a distinction between the Current State Buffer and the other sub-components of Working Memory, which seems to motivate this particular account, is in terms of the processes that operate within it. Representations are thought to be automatically registered in the Current State Buffer, without the need for rehearsal, this is not the case in the Visuospatial Sketchpad and the Phonological Loop, which may have their own specialised components for maintenance rehearsal, as I described in Chapters 1 and 2. It could be claimed therefore, that Working Memory sub-components are most likely to be characterised by a "storage" component and a "rehearsal" component. In this way, the sense is that the Current State Buffer's relationship to Working Memory is not equivalent to that of the Visuospatial Sketchpad and the Phonological Loop's relationship to Working Memory.

In this conception, the Current State Buffer is not subjugated by the Central Executive in the same way as the Phonological Loop and Visuospatial Sketchpad (which have been termed the "slave systems", e.g. Baddeley, 1985) are. This account therefore conceives of the Current State Buffer as a relatively distinct entity to Working Memory.

An alternative account is that the Current State Buffer somehow constitutes a more automated functioning of Working Memory, and that each sub-component of Working Memory has its own Current State Buffer in the same way that each component has a "storage" and "rehearsal" component. This follows from consideration of the fact that the independence of the Current State Buffer to Working Memory has been demonstrated with dual-task methodology, and is no different in many senses to the many demonstrations of the independence of the Visuospatial Sketchpad to the Phonological Loop. To this extent, the dissociation between the Visuospatial Sketchpad and the Current State Buffer may be no different to other dissociations within Working Memory.

There is no á priori reason to reject the idea of Current State Buffer function having a modality-specific sub-component for each of the components of Working Memory. For this second account of the relationship between the Current State Buffer and Working Memory, these sub-components would be a part of the Visuospatial Sketchpad, or the Phonological Loop. However, they would remain more autonomous in their functioning in keeping with the ideas that I suggested above, that the Current State Buffer is relatively independent to Working Memory[42].

What should become clear from this discussion, is that the extent to which the Current State Buffer and Working Memory are related lies on a theoretical continuum which describes the possible balance between the independence of the Current State Buffer and Working Memory on the one extreme, and the integration of the two constructs on the other. Whatever the actual balance turns out to be, the basic point that emerges from this thesis remains in place; namely that both Working Memory and Current State Buffer representations constitute separate parts of Short Term Memory.

[42] If one were to conceive of one structurally distinct Current State Buffer, as in the first account, the buffer would have its own modality specific sub-components.

8.5 The Capacity of the Current State Buffer

During the course of the thesis (notably in Chapter 7), I have talked about the capacity of the Current State Buffer as if it were able to track a finite number of character locations. It is very important to specify exactly what is meant by this. The absolute capacity of the adult Current State Buffer is conceived of being very large such that people are able to track a variety of different objects, mental states and the like without there being any interference. Where "capacity" has been used in the context of a number of characters being stored in the Current State Buffer, this has simply referred to the number of characters sleeping in the receptacle set of the experimental situation; i.e., it is task specific. It is crucial then to define not only what representations are worthy of Current State Buffer status for a given individual in a given situation, but also to demarcate capacity boundaries for different types of Current State Buffer representations.

8.6 The Current State Buffer and Development

The aim of this thesis was to investigate the Current State Buffer. As I explained previously, the choice of a developmental subject population was for theoretical and practical reasons. Therefore, any large scale implications for cognitive development are more incidental than anything else, although the methodology may be useful in studying young children's visual Working Memory. The most significant theoretical finding of developmental interest, however, is that the age-related shift in Working Memory performance (both digit span and memory for object locations), is mirrored by a difference in Current State Buffer capacity, suggesting that it is a component of memory that will develop like any other.

Apart from the change in the Current State Buffer's capacity to track character locations between the ages of three and four, it is difficult at this stage to say precisely what the nature of the change is. However, two things can be said in connection with this. Firstly, although there are many important developmental changes which occur between the ages of three and four (e.g. Karmiloff-Smith, 1992; Gopnik and Astington, 1988), it is not a certainty to assume that developmental differences related to Current State Buffer functioning will necessarily emerge across these ages. Secondly, as I noted in Chapter 7, there were some age-related differences in the strategies that subjects adopted when pushed beyond their Current State Buffer capacity (see section 7.7.3.1 for 3-year-olds, and section 7.7.3.2 for 4-year-olds).

8.7 Conclusion

This thesis began with a survey of Short Term Memory: a construct which is typically constrained by a limited capacity. The take-home message of this thesis may therefore be that the capacity of humans to remember information in the short term is actually a fair amount greater than previously reckoned, since in addition to any information temporarily stored in Short Term Memory, we are automatically tracking and updating important stimuli in our immediate environments.

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Appendix 1: Experiments 1, 2 and 3

Object/Toy Locations: Raw Data for Individual Items.

$CH1$ refers to Character condition of Experiment 1, and $OB1$ to the Object condition. $CH2$ refers to the Character condition in Experiment 2 (i.e. Character2 condition) and so on. Each row represents an individual subject's responses (1 - correct, 0 - incorrect) on each type of toy/object.

AGE	CONDITION	CAR	CAT	CRAYON	LEGO	TEDDY
3	OB1	0	0	1	-	1
3	OB1	0	0	0	-	0
3	OB1	0	0	0	-	1
3	OB1	0	0	0	-	0
3	OB1	0	0	1	-	1
3	OB1	0	0	0	-	1
3	OB1	1	1	1	-	1
3	OB1	0	0	0	-	0
3	OB1	1	0	1	-	0
3	OB1	0	0	0	-	0
3	OB1	1	1	1	-	0
3	OB1	0	0	0	-	0
3	OB1	1	1	1	-	1
3	OB1	1	0	0	-	0
3	CH1	1	0	1	-	1
3	CH1	0	0	0	-	1
3	CH1	1	1	1	-	1
3	CH1	0	1	0	-	1
3	CH1	1	1	1	-	1
3	CH1	0	0	1	-	1
3	CH1	1	1	1	-	1
3	CH1	0	0	0	-	1
3	CH1	1	1	1	-	1
3	CH1	0	1	1	-	1
3	CH1	1	1	1	-	1
3	CH1	1	1	1	-	1
3	CH1	1	1	1	-	1
3	CH1	0	1	0	-	1

AGE	CONDITION	CAR	CAT	CRAYON	LEGO	TEDDY
3	OB2	0	0	0	-	1
3	OB2	0	0	0	-	1
3	OB2	1	1	0	-	1
3	OB2	0	0	0	-	0
3	OB2	1	1	1	-	0
3	OB2	0	0	1	-	0
3	OB2	1	1	1	-	1
3	OB2	1	0	1	-	1
3	OB2	1	1	1	-	1
3	OB2	1	1	0	-	0
3	OB2	0	1	1	-	0
3	OB2	0	0	0	-	0
3	OB2	0	1	1	-	1
3	OB2	0	0	0	-	0
3	CH2	1	1	1	-	1
3	CH2	1	1	0	-	1
3	CH2	1	1	1	-	1
3	CH2	1	0	0	-	1
3	CH2	1	1	1	-	1
3	CH2	0	1	1	-	1
3	CH2	1	1	1	-	1
3	CH2	0	0	0	-	1
3	CH2	1	1	1	-	1
3	CH2	0	1	1	-	1
3	CH2	1	1	1	-	1
3	CH2	1	0	1	-	1
3	CH2	1	1	1	-	1
3	CH2	0	1	0	-	1
3	OB3	1	1	1	-	1
3	OB3	0	0	1	-	0
3	OB3	1	0	1	-	1
3	OB3	0	0	0	-	0
3	OB3	1	0	0	-	1
3	OB3	0	0	0	-	0
3	OB3	0	0	0	-	0
3	OB3	0	0	0	-	0
3	OB3	1	1	1	-	0
3	OB3	0	0	0	-	0

AGE	CONDITION	CAR	CAT	CRAYON	LEGO	TEDDY
3	OB3	0	1	0	-	1
3	OB3	0	0	0	-	0
3	OB3	1	1	1	-	1
3	OB3	0	1	0	-	0
3	CH3	1	1	1	-	1
3	CH3	1	1	1	-	1
3	CH3	1	1	1	-	1
3	CH3	1	1	1	-	1
3	CH3	0	0	1	-	1
3	CH3	0	0	1	-	1
3	CH3	1	0	0	-	1
3	CH3	1	0	0	-	1
3	CH3	0	1	1	-	1
3	CH3	0	0	0	-	1
3	CH3	1	1	1	-	1
3	CH3	1	0	0	-	1
3	CH3	0	1	0	-	1
3	CH3	0	0	0	-	1
4	OB1	0	0	1	1	1
4	OB1	0	0	1	0	0
4	OB1	1	1	0	0	1
4	OB1	0	0	0	0	1
4	OB1	0	0	1	0	1
4	OB1	0	0	1	0	1
4	OB1	0	1	1	1	1
4	OB1	0	1	0	0	0
4	OB1	1	0	0	1	1
4	OB1	0	1	0	1	0
4	OB1	0	0	0	1	0
4	OB1	0	1	0	0	0
4	OB1	1	0	1	0	0
4	OB1	1	0	0	0	0
4	CH1	1	1	1	1	1
4	CH1	1	1	1	1	1
4	CH1	1	1	1	1	1
4	CH1	1	1	1	1	1
4	CH1	1	1	1	1	1
4	CH1	0	0	0	0	1
4	CH1	1	1	1	1	1

AGE	CONDITION	CAR	CAT	CRAYON	LEGO	TEDDY
4	CH1	0	1	0	0	1
4	CH1	1	1	1	1	1
4	CH1	0	1	0	0	1
4	CH1	1	1	0	1	1
4	CH1	0	1	0	0	1
4	CH1	1	1	0	1	1
4	CH1	0	0	0	1	1
4	OB2	0	1	0	0	1
4	OB2	0	0	0	0	0
4	OB2	1	1	0	1	1
4	OB2	1	1	0	1	0
4	OB2	1	1	1	0	1
4	OB2	0	1	0	0	1
4	OB2	0	1	1	1	0
4	OB2	0	0	0	1	1
4	OB2	1	1	1	1	1
4	OB2	1	0	0	0	0
4	OB2	1	1	1	1	1
4	OB2	0	0	1	1	0
4	OB2	0	0	0	1	1
4	OB2	0	0	0	0	1
4	CH2	1	1	1	1	1
4	CH2	0	0	0	0	1
4	CH2	1	1	1	0	1
4	CH2	0	1	0	0	1
4	CH2	1	1	1	1	1
4	CH2	0	1	0	1	1
4	CH2	1	1	1	1	1
4	CH2	1	0	1	1	1
4	CH2	1	1	1	1	1
4	CH2	1	1	1	1	1
4	CH2	1	1	0	1	1
4	CH2	0	1	0	0	1
4	CH2	1	1	1	1	1
4	CH2	0	0	0	1	1
4	OB3	0	1	1	0	1
4	OB3	0	0	0	0	0
4	OB3	1	0	0	0	1
4	OB3	0	0	0	0	0

AGE	CONDITION	CAR	CAT	CRAYON	LEGO	TEDDY
4	OB3	1	1	0	1	0
4	OB3	1	1	0	0	0
4	OB3	1	1	1	1	1
4	OB3	0	0	0	0	0
4	OB3	1	1	0	0	1
4	OB3	0	1	0	0	0
4	OB3	0	0	1	1	0
4	OB3	0	0	1	0	0
4	OB3	1	1	1	0	0
4	OB3	0	0	0	0	0
4	CH3	1	1	1	1	1
4	CH3	1	1	0	0	1
4	CH3	1	1	1	1	1
4	CH3	1	0	0	0	1
4	CH3	1	1	0	1	1
4	CH3	0	1	0	0	1
4	CH3	1	0	1	0	1
4	CH3	1	0	0	0	1
4	CH3	1	1	1	1	1
4	CH3	0	1	0	0	1
4	CH3	1	1	1	1	1
4	CH3	1	0	0	0	1
4	CH3	1	0	1	1	1
4	CH3	1	0	0	1	1

Correct Receptacles: Raw Data for Individual Items.

Each column represents the times that each of the receptacles was used to contain an object, with a 1 or 0 denoting whether the object was recalled correctly or incorrectly, respectively.

Condition	Bag	Basket	Bowl	Box	Cup	Hat	Sock
	0	0	0	1	1	1	1
3-YEAR-OLDS	0	0	0	0	0	0	1
	0	0	0	1	0	1	1
EXPERIMENT 1	0	0	0	0	0	0	0
	1	0	1	1	1	1	1
OBJECT	0	0	0	0	0	0	0
CONDITION	1	1	1	1	0	0	1
	0	0	1	0	0	0	0
	1	1	1	1	1	1	1
3-YEAR-OLDS	0	0	0	0	0	1	0
	0	1	1	1	1	1	1
EXPERIMENT 1	0	1	0	0	1	1	1
	1	1	1	1	1	1	1
CHARACTER	0	0	1	0	1	1	0
CONDITION	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	0	1	1	1	1	1	1
3-YEAR-OLDS	0	0	0	0	0	0	0
	0	1	1	1	1	1	1
EXPERIMENT 2	0	0	0	1	0	0	0
	0	1	0	1	1	0	1
OBJECT	0	0	0	1	1	0	0
CONDITION	1	0	1	1	1	0	0
	1	0	1	1	1	0	0

Condition	Bag	Basket	Bowl	Box	Cup	Hat	Sock
	1	1	1	1	1	1	1
3-YEAR-OLDS	0	0	0	0	0	0	0
	1	1	1	1	1	1	1
EXPERIMENT 2	1	0	0	0	1	1	0
	1	1	1	1	1	1	1
CHARACTER	1	1	1	0	1	1	1
CONDITION	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	0	1	1	1	1	1	1
3-YEAR-OLDS	0	0	0	0	0	0	0
	1	0	0	1	0	1	1
EXPERIMENT 3	1	0	0	0	0	0	0
	1	1	1	0	1	0	0
OBJECT	0	0	1	0	0	0	0
CONDITION	1	0	1	1	1	0	1
	0	0	0	0	0	0	0
	1	1	1	1	0	0	0
3-YEAR-OLDS	1	1	1	1	0	0	0
	1	1	0	1	0	1	1
EXPERIMENT 3	0	1	0	0	0	1	0
	1	0	1	1	1	1	0
CHARACTER	0	0	1	1	1	0	0
CONDITION	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	0	1	0	1	0	0	1
	0	0	0	0	0	0	1
4-YEAR-OLDS	0	1	1	0	1	1	0
	0	0	1	0	0	0	0
EXPERIMENT 1	1	0	1	0	1	0	1
	1	0	1	0	0	0	0
OBJECT	1	0	0	1	1	1	0
CONDITION	0	0	0	0	1	0	0
	1	1	1	1	1	0	0
	0	1	1	0	0	0	0

Condition	Bag	Basket	Bowl	Box	Cup	Hat	Sock
	1	1	1	1	1	1	1
	0	1	1	0	0	0	0
4-YEAR-OLDS	1	1	1	1	1	1	1
	0	1	1	0	1	1	1
EXPERIMENT 1	1	0	1	1	1	0	1
	0	0	1	0	1	0	0
CHARACTER	1	1	1	1	1	1	1
CONDITION	0	0	1	1	1	0	0
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	0	0	0	0	0	0	0
4-YEAR-OLDS	1	0	1	1	1	1	0
	0	0	0	0	0	0	0
EXPERIMENT 2	0	1	0	0	1	1	0
	0	1	0	0	0	0	0
OBJECT	0	1	1	1	1	1	0
CONDITION	0	1	1	1	0	1	0
	0	1	1	1	1	1	1
	0	1	1	1	1	1	1
	1	1	1	1	1	1	1
	0	0	0	0	1	0	0
4-YEAR-OLDS	1	1	1	1	1	1	1
	0	0	0	1	1	0	0
EXPERIMENT 2	1	0	1	1	1	0	1
	0	0	1	1	1	0	0
CHARACTER	1	1	1	1	1	1	1
CONDITION	0	1	1	1	1	1	1
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1
	0	0	1	1	1	1	1

Condition	Bag	Basket	Bowl	Box	Cup	Hat	Sock
	0	0	0	0	1	0	0
4-YEAR-OLDS	1	0	1	1	1	1	0
	0	0	1	1	0	0	0
EXPERIMENT 3	0	1	1	0	0	1	1
	0	0	0	0	0	1	0
OBJECT	0	1	0	0	0	0	1
CONDITION	0	0	0	0	0	0	0
	0	1	0	1	0	1	1
	0	0	0	0	0	0	0
	1	1	1	1	1	1	1
	1	1	1	1	0	1	0
4-YEAR-OLDS	0	1	1	1	0	1	1
	0	0	1	1	0	1	0
EXPERIMENT 3	1	1	1	0	1	1	1
	0	0	0	0	0	0	0
CHARACTER	0	1	1	1	1	1	1
CONDITION	0	0	1	0	0	0	0
	1	1	1	1	1	1	1
	1	1	1	1	1	1	1

Appendix 2: Experiments 4, 5, 6 and 7

Each row represents an individual subject's response to the probing for the location of the three objects, given as correct (1) or incorrect (0).

SUBJECT	CONDITION	OBJECT 1	OBJECT 2	OBJECT 3
1	EXPERIMENT 4	1	1	1
2	EXPERIMENT 4	1	0	0
3	EXPERIMENT 4	1	1	1
4	EXPERIMENT 4	1	1	1
5	EXPERIMENT 4	1	1	1
6	EXPERIMENT 4	0	0	1
7	EXPERIMENT 4	1	1	1
8	EXPERIMENT 4	0	0	1
9	EXPERIMENT 4	1	0	1
10	EXPERIMENT 4	1	1	0
11	EXPERIMENT 4	0	1	0
12	EXPERIMENT 4	0	1	0
13	EXPERIMENT 4	1	1	1
14	EXPERIMENT 4	0	1	1
15	EXPERIMENT 5	1	1	1
16	EXPERIMENT 5	1	0	0
17	EXPERIMENT 5	0	0	0
18	EXPERIMENT 5	0	0	1
19	EXPERIMENT 5	1	0	0
20	EXPERIMENT 5	0	0	0
21	EXPERIMENT 5	1	0	1
22	EXPERIMENT 5	0	0	1
23	EXPERIMENT 5	0	0	1
24	EXPERIMENT 5	0	1	0
25	EXPERIMENT 5	1	1	1
26	EXPERIMENT 5	0	1	0
27	EXPERIMENT 5	1	0	0
28	EXPERIMENT 5	0	0	0

SUBJECT	CONDITION	OBJECT 1	OBJECT 2	OBJECT 3
29	EXPERIMENT 6	1	0	0
30	EXPERIMENT 6	1	1	1
31	EXPERIMENT 6	0	0	1
32	EXPERIMENT 6	1	0	1
33	EXPERIMENT 6	1	1	1
34	EXPERIMENT 6	1	1	1
35	EXPERIMENT 6	1	1	1
36	EXPERIMENT 6	1	1	1
37	EXPERIMENT 6	0	0	0
38	EXPERIMENT 6	1	0	1
39	EXPERIMENT 6	0	0	0
40	EXPERIMENT 6	1	0	0
41	EXPERIMENT 6	1	1	0
42	EXPERIMENT 6	1	1	0
43	EXPERIMENT 7	1	1	1
44	EXPERIMENT 7	0	1	0
45	EXPERIMENT 7	1	1	1
46	EXPERIMENT 7	1	1	1
47	EXPERIMENT 7	1	1	0
48	EXPERIMENT 7	0	0	0
49	EXPERIMENT 7	1	0	0
50	EXPERIMENT 7	1	1	0
51	EXPERIMENT 7	1	1	1
52	EXPERIMENT 7	1	0	0
53	EXPERIMENT 7	1	1	0
54	EXPERIMENT 7	0	1	0
55	EXPERIMENT 7	0	0	1
56	EXPERIMENT 7	1	1	1

Appendix 3: Experiments 8 and 9

Raw Data for each Subject's Recall of the Object and Character Locations

Each row represents an individual subject's response to the object location probes (T1 to T4) and character location probes (C1 to C3). The responses are in terms of which (used) receptacle they indicated that the probed object or character was hidden in. *NA* denotes "not applicable", *DK* denotes a "don't know" response, and 0 denotes the response of a receptacle that did not have anything hidden inside it. *2CHAR-CH* denotes the Character condition in Experiment 8, and *2CHAR-OB* the Object condition, *3CHAR-CH* and *3CHAR-OB* are the Character and Object conditions in Experiment 9, respectively.

SUBJECT	AGE	CONDITION	T1	T2	T3	T4	C1	C2	C3
1	3	2CHAR-CH	T1	T2	T3	NA	C1	0	NA
2	3	2CHAR-CH	T1	T2	T3	NA	C1	C2	NA
3	3	2CHAR-CH	T1	T2	0	NA	C1	C2	NA
4	3	2CHAR-CH	T1	T2	T3	NA	C1	T1	NA
5	3	2CHAR-CH	T1	T2	T3	NA	C1	C2	NA
6	3	2CHAR-CH	T1	0	T3	NA	C1	C2	NA
7	3	2CHAR-CH	C1	T3	0	NA	0	C2	NA
8	3	2CHAR-CH	T3	T2	T3	NA	C1	C2	NA
9	3	2CHAR-CH	0	T3	T1	NA	C1	C2	NA
10	3	2CHAR-CH	T1	T2	T3	NA	C1	C2	NA
11	3	2CHAR-CH	T1	T2	C1	NA	C1	T2	NA
12	3	2CHAR-CH	T2	T3	T1	NA	T2	C2	NA
13	3	2CHAR-CH	T1	T2	0	NA	C1	0	NA
14	3	2CHAR-CH	T1	T2	T3	NA	C1	C2	NA
15	3	2CHAR-OB	T2	C2	C1	NA	T1	C2	NA
16	3	2CHAR-OB	T1	T2	DK	NA	C1	DK	NA
17	3	2CHAR-OB	T1	C1	T2	NA	C2	T3	NA
18	3	2CHAR-OB	T3	T2	C1	NA	T3	C2	NA
19	3	2CHAR-OB	C2	0	T3	NA	C1	0	NA
20	3	2CHAR-OB	T1	0	T2	NA	0	C2	NA
21	3	2CHAR-OB	T2	0	T3	NA	T1	C1	NA
22	3	2CHAR-OB	T3	T2	C1	NA	T1	C2	NA
23	3	2CHAR-OB	0	T1	T1	NA	C1	T2	NA

SUBJECT	AGE	CONDITION	T1	T2	T3	T4	C1	C2	C3
24	3	2CHAR-OB	T1	T1	0	NA	T2	T3	NA
25	3	2CHAR-OB	T1	T3	C2	NA	0	0	NA
26	3	2CHAR-OB	T1	T2	T3	NA	C1	C2	NA
27	3	2CHAR-OB	C1	C2	T3	NA	T1	T3	NA
28	3	2CHAR-OB	C2	0	T3	NA	T1	T3	NA
29	3	3CHAR-CH	C1	C3	C2	NA	T3	0	C2
30	3	3CHAR-CH	T1	T2	T3	NA	C1	C2	C3
31	3	3CHAR-CH	C3	T2	T2	NA	C1	C1	C1
32	3	3CHAR-CH	T1	T3	T2	NA	C2	C3	C1
33	3	3CHAR-CH	T3	T2	C1	NA	C2	C3	T1
34	3	3CHAR-CH	C3	T3	T1	NA	C3	C2	C1
35	3	3CHAR-CH	T1	C3	C1	NA	C2	C1	C3
36	3	3CHAR-CH	T1	T2	T3	NA	C1	C2	C3
37	3	3CHAR-CH	C1	T2	T3	NA	C2	C1	C3
38	3	3CHAR-CH	C2	T1	C1	NA	T3	C3	0
39	3	3CHAR-CH	T1	T2	C3	NA	C1	0	C2
40	3	3CHAR-CH	T1	DK	T3	NA	C2	C1	C3
41	3	3CHAR-CH	C1	C2	C3	NA	C1	C2	C3
42	3	3CHAR-CH	T1	C3	T2	NA	C1	T1	C3
43	3	3CHAR-OB	DK	T2	DK	NA	C1	T1	C1
44	3	3CHAR-OB	T1	T2	DK	NA	C3	C2	C1
45	3	3CHAR-OB	C3	T2	T2	NA	C3	T3	C3
46	3	3CHAR-OB	C3	C2	0	NA	T3	C1	T2
47	3	3CHAR-OB	T3	C1	0	NA	T3	C1	C2
48	3	3CHAR-OB	T1	T2	T3	NA	C1	C2	0
49	3	3CHAR-OB	T1	DK	C2	NA	C1	T2	T3
50	3	3CHAR-OB	DK	0	T3	NA	C2	T1	T3
51	3	3CHAR-OB	C3	T1	T3	NA	T2	T1	C1
52	3	3CHAR-OB	C2	C3	T3	NA	C1	T2	T1
53	3	3CHAR-OB	0	T3	T1	NA	C2	DK	C1
54	3	3CHAR-OB	T1	C2	T2	NA	C1	T3	C3
55	3	3CHAR-OB	T1	T2	C3	NA	DK	DK	0
56	3	3CHAR-OB	T1	C3	C2	NA	0	C1	T3
57	4	2CHAR-CH	T4	T2	T1	T3	C1	C2	NA
58	4	2CHAR-CH	T1	T4	T2	T4	C1	C2	NA
59	4	2CHAR-CH	0	T2	T1	T3	C1	T3	NA
60	4	2CHAR-CH	T3	T2	T1	T4	C1	C2	NA
61	4	2CHAR-CH	T1	T4	T3	C2	C1	0	NA
62	4	2CHAR-CH	T1	T2	T3	T4	C1	C2	NA

SUBJECT	AGE	CONDITION	T1	T2	T3	T4	C1	C2	C3
63	4	2CHAR-CH	T1	T2	T3	T4	C1	C2	NA
64	4	2CHAR-CH	T2	T3	T4	T4	C1	C2	NA
65	4	2CHAR-CH	T2	T1	T3	T4	C1	C2	NA
66	4	2CHAR-CH	T4	T3	T3	T1	C1	C2	NA
67	4	2CHAR-CH	T1	T2	T3	T4	C1	C2	NA
68	4	2CHAR-CH	T2	T1	T3	T4	C1	C2	NA
69	4	2CHAR-CH	DK	T2	T3	T4	C1	C2	NA
70	4	2CHAR-CH	T2	0	T3	T4	C1	C2	NA
71	4	2CHAR-OB	T1	T2	0	C1	T3	C2	NA
72	4	2CHAR-OB	T1	T4	DK	T3	C2	C1	NA
73	4	2CHAR-OB	T1	T2	T3	T4	C2	C1	NA
74	4	2CHAR-OB	T1	C2	T3	C1	0	T4	NA
75	4	2CHAR-OB	T1	T2	T3	T4	C1	C2	NA
76	4	2CHAR-OB	T1	T2	T3	C2	C1	0	NA
77	4	2CHAR-OB	T1	C2	0	T3	C1	T2	NA
78	4	2CHAR-OB	T2	C1	0	C1	T1	C2	NA
79	4	2CHAR-OB	T3	0	C1	T4	C1	T4	NA
80	4	2CHAR-OB	C1	T3	T3	T4	C1	C2	NA
81	4	2CHAR-OB	C1	0	T4	T1	C1	C2	NA
82	4	2CHAR-OB	T3	T4	0	C2	T2	C1	NA
83	4	2CHAR-OB	T2	T2	T3	T4	C1	C2	NA
84	4	2CHAR-OB	T4	T2	T1	0	C2	C2	NA
85	4	3CHAR-CH	T4	T2	T3	C1	T1	C2	T2
86	4	3CHAR-CH	T1	T2	T4	T3	T1	C1	C2
87	4	3CHAR-CH	T4	T2	C1	T4	T2	T3	C3
88	4	3CHAR-CH	C2	T2	T3	T4	T1	C3	C2
89	4	3CHAR-CH	C2	T4	T1	T2	C1	T1	C3
90	4	3CHAR-CH	T3	C3	C2	T3	T2	C2	C3
91	4	3CHAR-CH	T1	T2	T4	T3	C2	C1	C3
92	4	3CHAR-CH	T1	C3	T4	T2	C2	C2	T3
93	4	3CHAR-CH	C3	C1	T2	T4	C2	C2	C1
94	4	3CHAR-CH	T1	T2	T4	T3	C1	C2	C3
95	4	3CHAR-CH	T1	T2	T3	T4	C1	C3	C2
96	4	3CHAR-CH	T1	T2	C3	C1	T4	C3	C1
97	4	3CHAR-CH	T1	T2	T3	DK	C1	C2	C3
98	4	3CHAR-CH	T1	T3	C3	T4	C1	C2	C3
99	4	3CHAR-OB	C2	C1	T2	C2	C1	T4	C3
100	4	3CHAR-OB	T1	C3	T2	T3	C2	T4	C1
101	4	3CHAR-OB	T1	T4	T3	T2	C2	C1	C1

102	4	3CHAR-OB	C2	T2	T3	T4	C3	C1	T1
103	4	3CHAR-OB	C1	T2	C3	T2	T3	T1	C3
104	4	3CHAR-OB	T2	T4	T1	C2	C3	C1	T3
105	4	3CHAR-OB	T3	T2	C2	T4	C1	C2	T1
106	4	3CHAR-OB	T1	T2	T3	T4	C3	C1	T4
107	4	3CHAR-OB	T1	T2	C1	C2	C3	T4	C2
108	4	3CHAR-OB	T2	T4	C3	C2	C3	T4	C3
109	4	3CHAR-OB	T1	T2	T3	C1	C3	C2	T3
110	4	3CHAR-OB	C3	T2	C3	T4	C1	C3	C1
111	4	3CHAR-OB	T1	T2	C3	C2	C2	T4	T3
112	4	3CHAR-OB	C2	C1	T4	T3	C1	T1	T2

Mean Total Errors in Experiments 8 and 9 and Class of Error as a Proportion of Total Error

"O-e" denotes the confusion of the location of an object to either a non-used receptacle or the response of 'don't know' to an object probe. "C-e" denotes the same type of errors, but following a probe for a character location. See section 7.5 for other abbreviations.

				Proportion of total Errors					
Age	No. Of Characters	Condition	Error Total	O-o	C-c	O-c	C-o	O-e	C-e
3	2	CHAR	1.43	**0.27**	**0.01**	**0.08**	**0.18**	**0.31**	**0.18**
3	2	OBJ	3.29	**0.21**	**0.04**	**0.21**	**0.24**	**0.07**	**0.13**
3	3	CHAR	3.57	**0.15**	**0.37**	**0.33**	**0.07**	**0.03**	**0.06**
3	3	OBJ	4.29	**0.09**	**0.19**	**0.19**	**0.24**	**0.14**	**0.15**
4	2	CHAR	1.93	**0.76**	**0.00**	**0.03**	**0.02**	**0.16**	**0.03**
4	2	OBJ	3.29	**0.30**	**0.14**	**0.24**	**0.11**	**0.15**	**0.06**
4	3	CHAR	3.79	**0.32**	**0.24**	**0.20**	**0.16**	**0.07**	**0.00**
4	3	OBJ	4.79	**0.18**	**0.28**	**0.30**	**0.23**	**0.00**	**0.00**

Appendix 4: Miscellaneous

Photograph of All the "Characters" together

Bunny, Simba, Hans and Teddy (from left to right) are all of equal size

Example of a Specially Prepared Response Sheet Used in Experiment 1 (Stimulus Randomisation #1)

EXPERIMENT 1: RANDOMISATION 1

3-year-olds

TEDDY	BOX
CAR	BASKET
CRAYON	BOWL
CAT	HAT

	DOB	D.S.	CAR	CRAYON	CAT	TEDDY
Character condition						
Object condition						

4-year-olds

TEDDY	BOX
CAR	BASKET
CRAYON	BOWL
CAT	HAT
LEGO	CUP

	DOB	D.S.	CAR	CRAYON	CAT	TEDDY
Character condition						
Object condition						